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SAVING MONEY THROUGH COMBUSTION CONTROL 5

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SAVING MONEY THROUGH COMBUSTION CONTROL 5

Saving money through Combustion Control

Introduction:

Virtually every industrial enterprise has boilers, furnaces and other combustion equipment such as kilns and ovens. This booklet is designed to help Canadian companies to maximize the efficiency of combustion processes — and, as a result, to save substantial amounts of energy and money.

The potential also exists in some plants to utilize waste material as a source of heat. And to help foster implementation of waste utilization systems, a section of the text deals with applications for pyrolysis incinerators.

Furnaces, Kilns, and Ovens

Roughly eleven percent of the nation's energy is used by industry for "direct heating" (not including indirect heating by steam). The majority of this energy is used by large plants in heavy industry such as primary metals, oil refining, or cement manufacturing. However, much of this energy is used by smaller organizations to heat treat metal parts, fire ceramics, dry paint, bake bread, and many other heating operations. This section is intended to describe how one can save energy in furnaces, kilns, and ovens.

In small energy-intensive organizations, the energy audit will quite frequently show that much of the energy is going to one or more pieces of direct fired equipment such as a furnace, kiln, dryer, etc. The success of an energy management programme will then depend on the decisions as to just what steps are most appropriate for energy savings in these pieces of equipment.

Making such decisions, and making them intelligently, is not something that can be done by any simple rule-of-thumb. Of course, check-lists can be used which describe the possible steps for increasing the energy efficiency of heating equipment, but nothing in such lists weighs the relative importance of the various check-list items. In other words, in one installation the most important first step may be adjusting the air to fuel ratio, in another the lack of insulation may be the important factor, and in a third it is possible that no major energy saving programme is justified.

The tool which will enable one to estimate the amount of energy which might be conserved and will point out the best ways of doing it, is the heat, or energy, balance. It will permit the translation of measurements and calculations to dollars of fuel savings.

Heat balances and how to use them

A heat balance is simply a measure of efficiency — a listing of the energy in all forms that enters a system over a given period of time (the input) and a similar listing of the energy that leaves (the output). Since energy is neither created nor destroyed, the input and the output must be equal.

For an energy management programme, a heat balance on a critical furnace or oven serves several purposes.

- It will show how much of the energy input was actually used for the intended purpose, e.g., to heat the product, to drive off water, etc. This figure may be interpreted as the energy efficiency of the system; it is in practice often as low as 2-5%.
- It will show how much of the energy is lost to the atmosphere or perhaps to a cooling pond. This, of course, represents energy savings that are theoretically possible.
- If the heat balance is reasonably well done, it will show also how the heat loss occurs. Some will be carried out with the product, some lost up the stack, some radiated to the surroundings from the furnace walls, etc. This information furnishes clues as to where one should look for the most important energy conservation possibilities.
- Most important of all, a heat balance is by far the best tool which one can use to estimate the

energy and cost savings which can be achieved by some change in process or equipment that is proposed as an energy saving investment. It will also enable one to identify the most valuable of several conservation proposals.

As an illustration, consider a simple system for the job of heating a pint of water from 22°C to boiling using a heavy cast iron skillet on the large burner of a kitchen stove. Tests show that it requires two cubic feet of gas, or 2000 Btu's to do the job. This 2000 Btu is the input energy to the system. The system output is in three parts. The energy needed to heat the water from 22°C to 100°C can be calculated at 140 Btu, while the energy necessary to heat the 3.5 pound skillet is about 60 Btu. The third output, some 1800 Btu, must be the energy in the hot combustion products which was lost to the atmosphere of the kitchen. The efficiency of this system is 140 Btu divided by 2000 Btu, or 7%.

A more efficient system than this would use a glass laboratory beaker as the container and a small electrical immersion heater as the energy source. The heat to the container would be cut to 10 Btu, and the loss to the surrounding air to about 50 Btu, requiring an input of electrical energy on only 200 Btu. Assuming that about 600 Btu of fossil fuel was required to generate this electricity, the efficiency has been increased to 140 Btu divided by 600 Btu, or 23%.

The important point of the above illustration is that the heat balance permitted the identification of the most important of the energy losses — the large amount of energy escaping around the skillet. It does not, however, mean that resistance heating is more efficient than fossil fuel fired heating.

Improvements to a furnace—an example.

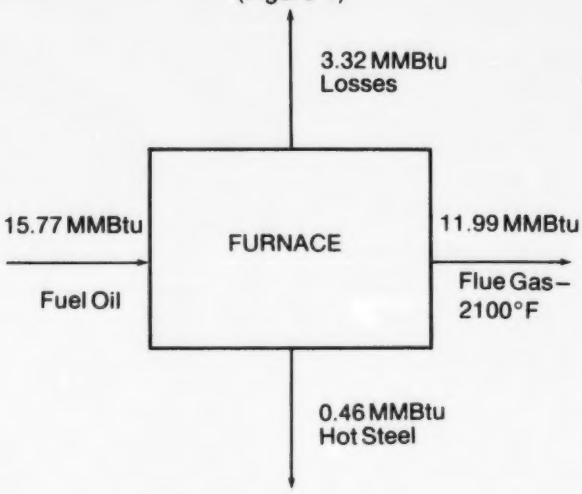
As an industrial example of this priciple, an oil-fired furnace heats one-ton batches of steel to 1093°C for a forging operation. It burns 95 gallons of # 2 fuel oil during each two-hour cycle. The stack temperature is 1149°C, and an analysis of the flue gas shows an oxygen content of 11%, equivalent to 100% excess air.

The only energy input to this system is the burning fuel oil. At an energy content of 166,000 Btu per gallon for # 2 oil,

Input = 166,000 Btu/gal × 95 gal = 15.77 MMBtu.

1st Heat Balance—Batch Fired Furnace

(Figure 1)



This same quantity of energy must also leave the furnace during each cycle; it does so in three forms:

1. The heat content of the steel is the weight of steel times its temperature increase times its specific heat of 0.12 Btu/lb°F = 0.46 MM Btu.
2. The stack loss represents the energy escaping in the hot flue gas. Referring to the chart, note that at a stack temperature of 1149°C, and with 100% excess air, the stack loss is 76% of the fuel burned.
   Stack loss = 15.77 MMBtu × 0.76 = 11.99 MMBtu.
3. Conduction and radiation losses from the furnace walls and roof must make up the remainder of the energy output.
   Wall losses: 15.77 − (11.99 + 0.46) = 3.32 MMBtu.

Output = 0.46 + 11.99 + 3.32 = 15.77 MMBtu per cycle.

It is evident in this heat balance that most (76%) of the energy is wasted up the exhaust stack. Looking again at the chart, one can observe that the stack loss is least when the amount of combustion air is precisely the amount required to completely burn the fuel. If large amounts of excess air are supplied, the energy of the fuel is mostly used to heat the air, and the stack loss becomes very large. Conversely, of course, if insufficient air is supplied, the fuel will not be completely burned and energy will again be wasted. A reasonable quantity of excess air

when burning fuel oil is about 20%, or when burning natural gas about 5-10%.

Excess air can be reduced by adjusting the burners, by throttling the air inlets, and by repairing cracks, holes, and ill-fitting doors. The stack damper should also be adjusted to maintain a very slight positive pressure in the fire-box to prevent the infiltration of unwanted air. The goal of 20% excess air is reached when the flue gas analysis shows 3-3.5% oxygen and 11.5-12% carbon dioxide.

At 20% excess air, the chart shows that the stack loss is only 46% of the fuel energy instead of the original 76%. The energy absorbed by the steel remains at 0.46 MMBtu per cycle, and the loss from the walls and roof is still 3.32 MMBtu. This total, 3.32 + 0.46 = 3.78 MMBtu, is now 54% of the total input (100% − 46% = 54%). The total fuel energy needed per cycle is therefore:

3.78 MMBtu / 0.54 = 7.00 MMBtu

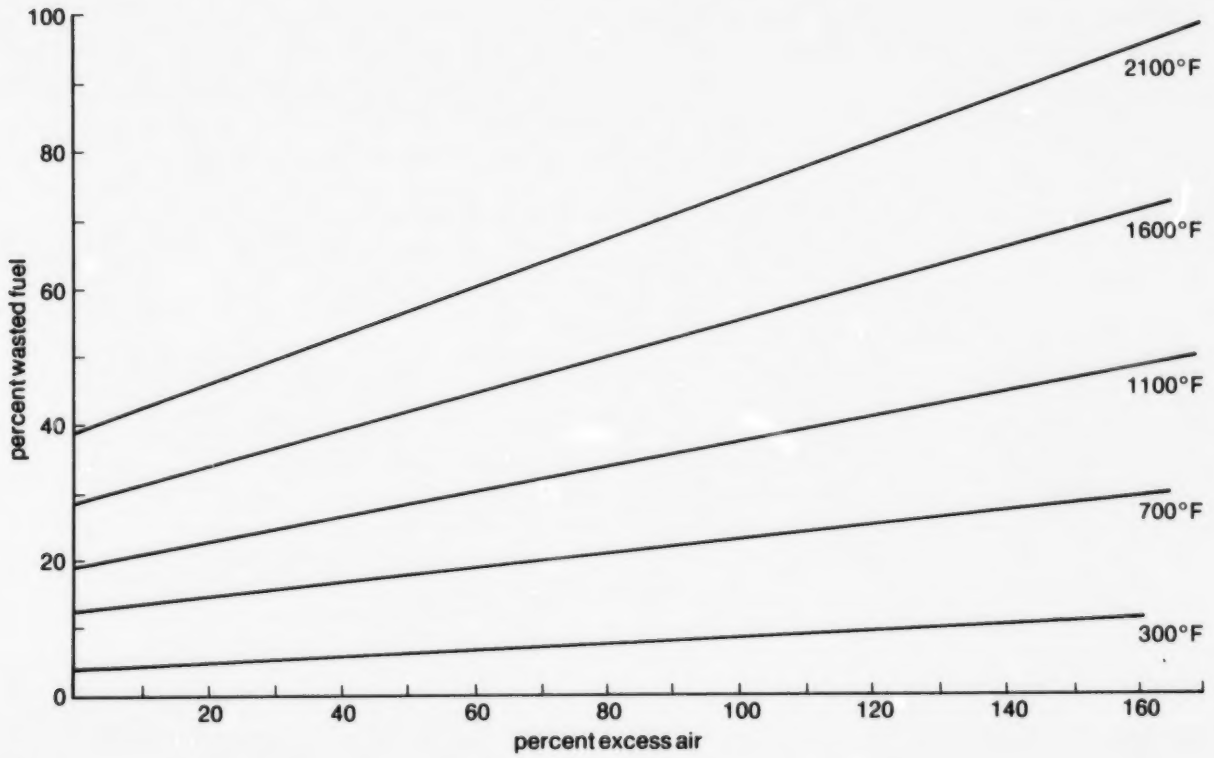
2nd Heat Balance

Input	*Output*
7.00 MMBtu	Steel − 0.46
= 42.3 gal (U.S.)	Stack − 3.22
of oil	Walls − 3.32
	Total − 7.00 MMBtu

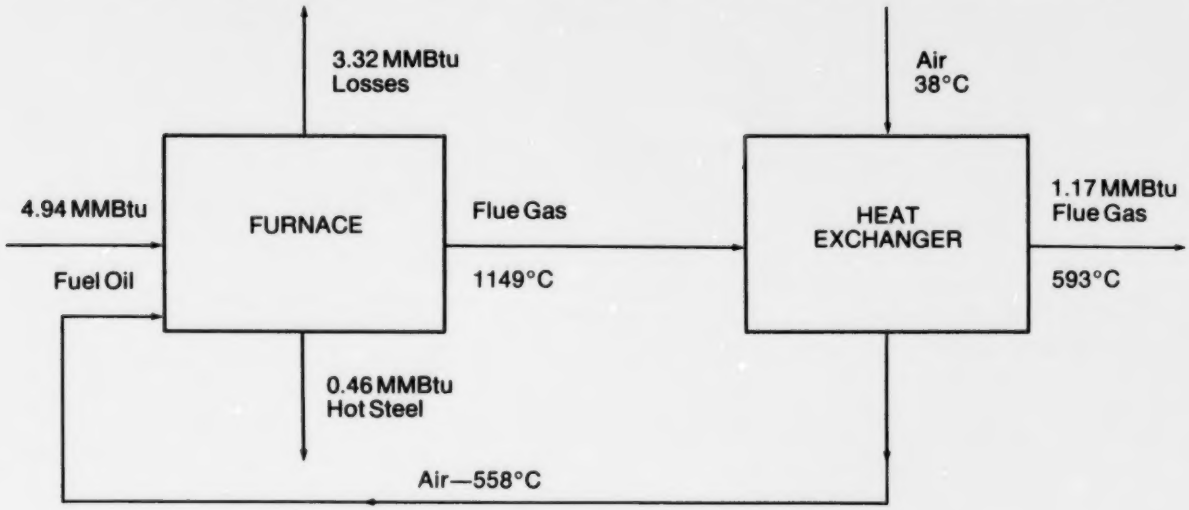
In the previous heat balance, even after adjusting the excess air to the practical minimum, energy is being wasted up the stack at the rate of 3.22 MMBtu per cycle, or at 500 cycles per year, 1365 MMBtu per year. With oil at 50¢ per gallon (U.S.), this is a dollar loss of $4,850 per year.

Some of this heat can be recovered by passing the flue gas through a heat exchanger, or through a waste heat boiler. The recovered heat can be used for a variety of purposes; following are some of those frequently suggested:

Stack Loss vs. Excess Air at various stack temperatures
(Figure 2)



3rd Heat Balance–Batch Furnace with Preheated Combustion Air (Figure 3)



- Make steam for process use, for electrical power generation, or for space heating.
- Heat water for processing or for space heating.
- Preheat combustion air for the furnace.
- Preheat the product entering the furnace.
- Heat air for space heating.

The best use for the recovered heat depends on the process and the particular plant conditions. In this case, with a batch furnace and possibly a rather uneven schedule, preheating the combustion air might be the best use. A diagram showing the heat flow with such an arrangement is shown as a 3rd heat balance. The numbers are MMBtu's of energy for a two hour furnace cycle.

To estimate the fuel usage under these conditions, consider the entire diagram as a single system with one heat input (the air at 100°F is considered to carry no heat), and three outputs. Two of the outputs are the heat in the steel, and the conduction losses. These outputs total 3.78 MMBtu as in heat balance No. 2. The third output is the waste flue gas at 1100°F. (Since the mass of flue gas is approximately equal to the mass of combustion air, it is reasonable to estimate that if the air is heated by 1000°F, the flue gas will be cooled by the same amount.)

According to the chart, at 20% excess air and a stack temperature of 1100°F, the stack loss is 23.5% of the fuel fired. The other two outputs, the 3.78 MMBtu for conduction losses and for the hot steel, must therefore, amount to 100% − 23.5% = 76.5% of the fuel.

Fuel energy = 3.78 × 1/0.765 = 4.94 MMBtu per cycle.

Stack loss = 4.94 × 0.235 = 1.17 MMBtu per cycle.

At this point, the largest energy loss in the system is the 3.32 MMBtu lost by conduction and radiation through the walls and roof of the furnace. Assume that suitable repair or addition to the insulation can reduce this loss to 1.70 MMBtu per cycle. A new heat balance performed as shown above determines that this will reduce the fuel input to 2.82, and the stack loss to 0.66 MMBtu per cycle.

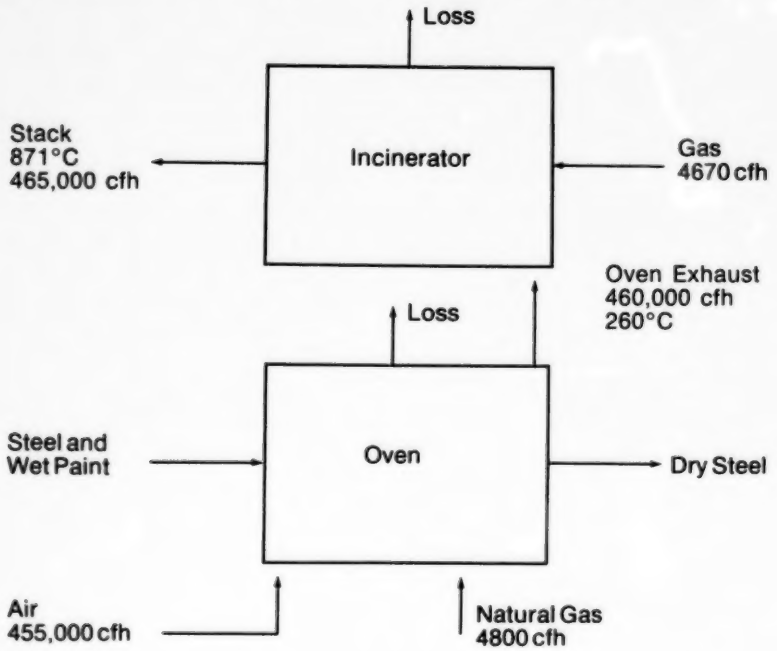
SUMMARY TABULATION
MMBtu per TWO HOUR CYCLE

	Input MMBtu	Stack Loss	Conduction Loss	Heat in Steel	Efficiency
1. Original condition	15.77	11.99	3.32	0.46	2.9%
2. Reduce excess air	7.00	3.22	3.32	0.46	6.6%
3. Preheat air	4.94	1.17	2.72	0.46	9.3%
4. Add insulation	2.82	0.66	1.70	0.46	16.3%

Assuming a production rate in this furnace of 500 cycles per year, and an average fuel oil cost of 50¢ per gallon, the yearly cost of energy under the four different conditions is as follows:

1. Original condition	$23,750
2. Reduce excess air	10,540
3. Preheat air	7,440
4. Add insulation	4,250

Conventional Paint Dryer and Fume Incinerator (Figure 4)



Obviously, these changes were not all of equal importance. By far the most important was the reduction of excess air from 100% to 20%. This single change saves $13,210 per year, and the capital cost involved is quite minor.

The next change, that of preheating the air, produced a smaller savings of $3,100. The cost. of a heat exchanger, duct work, and probable burner modifications will vary widely with different installations. If, in this case, the cost were $2,500, it would be a very attractive proposition; a quotation of $10,000 would require some rather careful analysis before making the investment. If one assumes a continuing increase in energy costs even the latter figure might be within reason, however.

The third step, adding insulation, saved $3,190. The cost could be low if it consisted of the simple addition of some bats or blankets of ceramic fiber on the inside of the walls and roof, or higher if it required rebuilding of the entire furnace lining.

It is evident that there is no simple rule-of-thumb by which one can decide to take a certain series of energy saving steps in a specific order. Any intelligent decision requires a reasonable knowledge of the current situation and an estimate of the savings possible for each proposed step.

A paint drying oven — a conservation case.

Some continuous kilns or ovens, such as those used for brazing, annealing, sintering, etc., may be treated in much the same fashion as a batch furnace when estimating an energy balance.

It is only necessary to translate all energy units into Btu's per hour or per minute instead of Btu's per batch or cycle. The principles of energy management in these kilns are exactly the same — maintain the minimum practical fuel/air ratio, insulate properly, and recover waste heat whenever possible.

Other kilns, such as those used for drying a product containing water or an organic solvent, may be more complex systems. For example, the paint drying kiln discussed below must use so much air to dilute the combustible solvent vapors that the stack gas carries almost 1000% excess air. In this case, it is not practical to get an accurate analysis of the stack gas, and a measurement of the air flow rate is necessary in order to estimate a heat balance.

Consider a continous paint drying oven which is fed with 10,000 pounds of steel per hour, covered with 600 pounds of wet paint. The paint is composed of 290 pounds of solvent and 310 pounds of paint solids. The air in the oven is heated to 260°C with natural gas, which

evaporates the paint solvent (1190 cubic feet of vapor), and raises the temperature of the steel to 204°C. A large amount of excess air is required in order to prevent the formation of an explosive atmosphere of air and solvent vapor; the usual requirement is 10,000 cubic feet of excess air per gallon (about 7.25 lbs.) of solvent evaporated. Air pollution regulations state that the hydrocarbon vapors in the oven exhaust cannot be discharged directly into the atmosphere. The exhaust, therefore, is led into an incinerator where more natural gas is burned to raise the temperature from 260°C to 871°C. At this temperature the hydrocarbons are all oxidized to carbon dioxide and water, and may safely be sent up the stack. A flow diagram of the system is shown.*

Heat balance for a conventional paint dryer.

Input

Natural gas to oven	4.80 MMBtu/hr
Natural gas to incinerator	4.67
Solvent vapors*	5.33
Total	14.80 MMBtu/hr

Output

Hot dry steel	0.41 MMBtu/hr
Stack loss at 1600°F	12.90
Other loss and unaccounted	1.49
Total	14.80 MMBtu/hr

*Since the solvent has a heat of combustion of about 18,400 Btu/lb, it furnishes part of the energy of its own incineration which must be included as a part of the heat input.

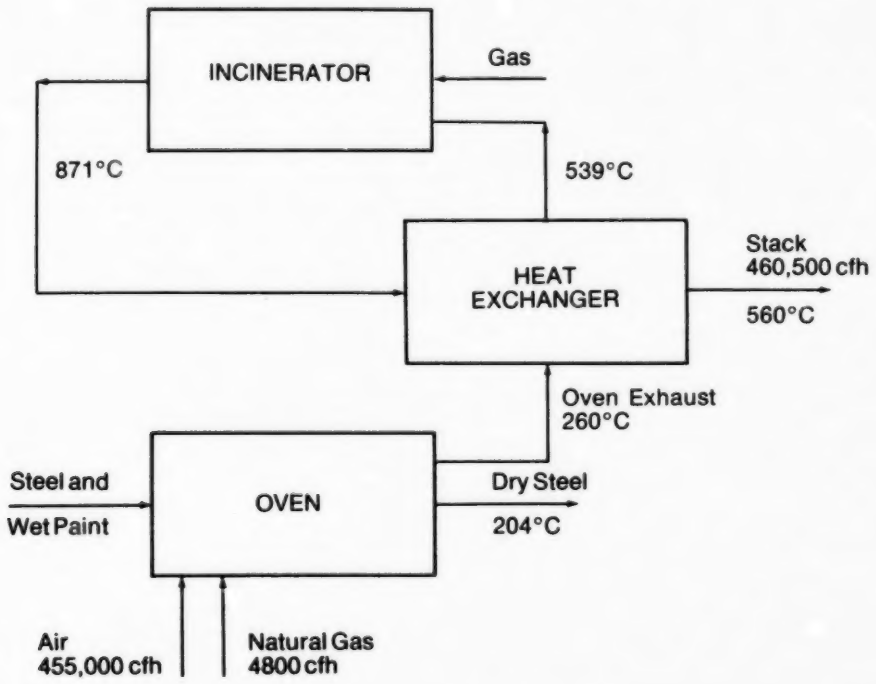
Inspection of this heat balance shows that the vast majority of the energy input, some 87%, is wasted as stack loss. Since this loss cannot be reduced by shutting down the incinerator, or by reducing the large amount of excess air, one must look for ways to utilize this waste heat. One technique is shown in the diagram, where a heat exchanger is used to recover part of the stack gas heat to preheat the overn exhaust before it enters the incinerator.

The following tabulation shows a heat balance on this new system:

Input

Natural gas to oven	4.80 MMBtu/hr
Natural gas to incinerator*	0
Solvent vapors	5.33
Total	10.13 MMBtu/hr

Paint Dryer, Fume Incinerator, and one Heat Exchanger (Figure 5)



Output

Hot dry steel	0.41 MMBtu/hr
Other losses	1.50
Stack loss at 1100°F	8.22
Total	10.13 MMBtu/hr

*A very small amount of fuel may be needed to assure that the gas stream ignites in the incinerator; i.e., a "pilot light".

Note that the addition of the heat exchanger and its accompanying duct work has reduced the use of natural gas from 9.47 MMBtu/hr to 4.80 MMBtu/hr. Assuming a natural gas cost of $2.00 per thousand cubic feet, and operation of the system for 4000 hours per year, the annual saving is

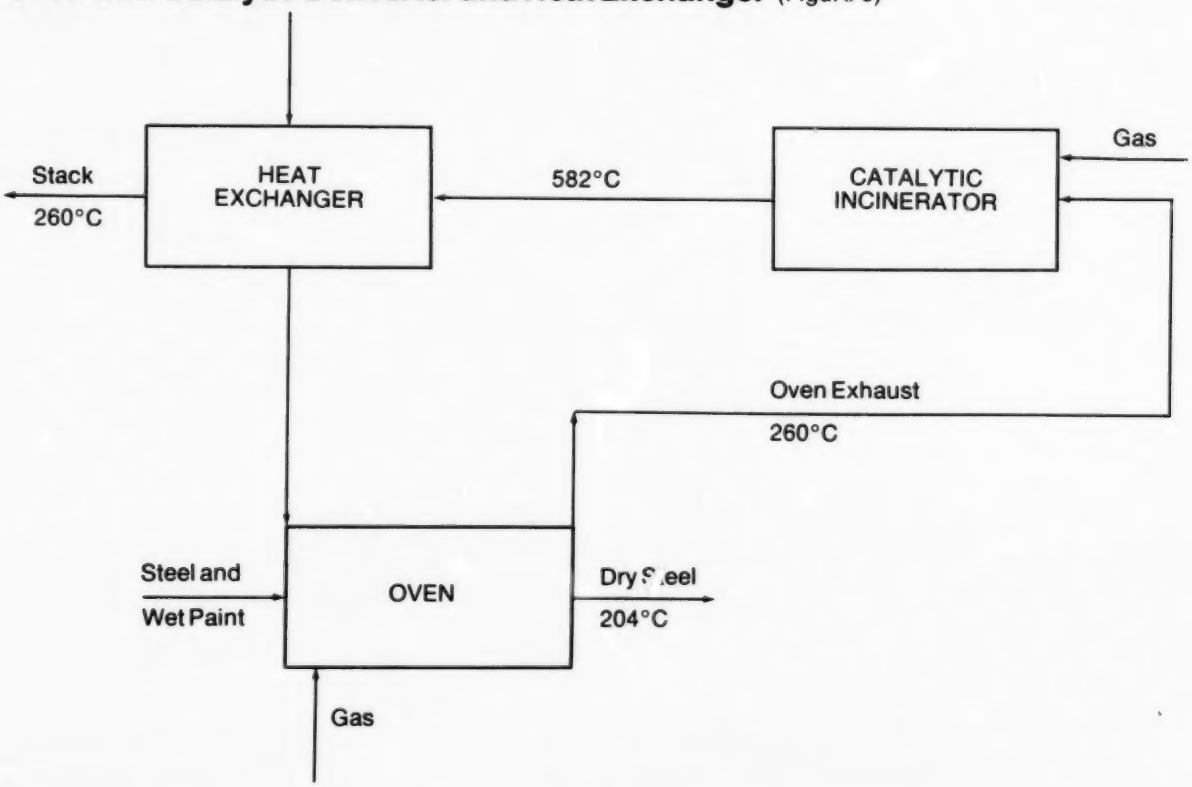
$$\frac{(9.47 - 4.80)\ \text{MMBtu/hr} \times 4000\ \text{hr/yr} \times \$2.00/\text{MFC}}{1000\ \text{Btu/cf}} = \$37{,}360\ \text{per year}$$

Although the heat exchanger has reduced the amount of purchased fuel considerably, there is still a large amount of waste heat in the exhaust flue gas. It is possible to use this heat by installing a second heat exchanger and using it to preheat the incoming air to the oven up to 316°C. This will require some modifications perhaps to the air distribution system within the oven, but it will do away completely with need to fire natural gas to the oven except during warm-up or when operating at very low product/throughput. At normal production, all the heat is furnished by burning the solvent vapors in the incinerator.

Another method of conserving energy when incinerating hydrocarbon fumes, is to use a catalytic incinerator, similar in principle to the catalytic converters on the exhaust system of modern automobiles. Such a catalytic incinerator can save energy because the fume combustion is carried out at much lower temperatures than the normal 871°C. Statements by manufacturers mention temperatures as low as 204°C for combustion of hydrocarbon vapors in excess air. The diagram shows a possible use of such a catalytic converter to a paint drying oven.

A heat balance for this system indicates that no heat from natural gas is needed when operating at a normal load. The gas burners indicated on the diagram will be necessary only during start-up, or when not enough product is being dried to furnish solvent vapor to heat the system.

Oven with Catalytic Converter and Heat Exchanger (Figure 6)



Input

Natural gas	0 MMBtu/hr
Solvent	5.33
Total	5.33 MMBtu/hr

Output

Hot dry steel	0.41 MMBtu/hr
Evaporation of solvent	0.06
Stack loss at 500°F	3.61
Other losses	1.25
Total	5.33 MMBtu/hr

Some catalysts are "poisoned" and cease to work properly, if the vapors contain sulfur compounds or heavy metals such as lead. This point should be checked with equipment manufacturers.

A third possible method of energy conservation in paint drying is the use of a patented incinerator which can produce an exhaust stream that is almost free of oxygen; 2% is reported. If this gas is used in the oven for heating the product, one can permit the concentration of solvent vapors to reach a much higher level without danger of reaching an explosive atmosphere. This means that the volume of gases to be circulated can be cut to about one-half, and that energy can also be saved in the electrical power needed to operate the fans and blowers.

A summary of the purchased cost of fuel for the three systems considered is as follows:

	Annual Fuel Cost[1]	Efficiency[2]
Fig. 4 Conventional Dryer	$75,700	2.8%
Fig. 5 Dryer & Heat Exchanger	$38,400	4.2%
Fig. 6 Catalytic Converter	[3]	7.7%

If the solvent dried from a paint film is valuable in itself, for reasons other than its fuel value, one should consider recovering it with an activated carbon tower instead of incinerating it. This will not, in general, constitute an energy saving, but may well be a financial gain. Some newer systems use a vacuum rather than heat to pull the absorbed solvent from the activated carbon, and are reported to use less energy than the older heating technique to recover the valuable solvent.

Drying ovens or kilns in general do not lend themselves to rule-of-thumb advice as to the best methods of energy conservation. Each kiln seems to have its own special features, and needs an individual heat balance in order to understand how best to conserve energy. Kilns almost inevitably, however, have large quantities of waste heat available. If this waste can be utilized for space heating, low pressure steam, hot water, etc., one can improve on the rather low efficiencies listed in the tabulations above.

(1) Assumes natural gas at $2.00 per thousand cubic feet, and operation for 4000 hours per year.

(2) Energy needed for the product divided by total energy, including that in the paint solvent.

(3) Natural gas is needed only during a start-up period, or when operating at a low production rate.

Opportunities for energy savings

There are, obviously, a wide variety of steps that can be taken to improve the efficiency of furnaces, kilns and ovens. What follows is a list and brief description of the major opportunities.

Control of Excess Air.

The use of a greater amount of combustion air than is necessary can constitute a major energy waste. Certainly, the use of insufficient air is just as wasteful, but probably less common due to recent emphasis on air pollution problems, particularly visible smoke formation.

There is no accurate data on just how much excess air is used in the "average" furnace, or how much energy is wasted annually due to poor control of air/fuel ratios. And care should be taken in attempting to estimate the energy savings achievable through a reduction in excess air. For example, reducing the amount of combustion air, with no change in the rate at which fuel is fired, may result in a higher flame temperature and a more rapid heating of the work and a shorter, energy saving, cycle.

If in addition to reducing air flow, the fuel flow is also reduced, there will be a decreased gas velocity and less turbulence in the furnace, and an increased residence time of the hot gases within the combustion chamber. But the exact effect of these changes on heat transfer to the work and to the furnace walls, is not always evident or readily estimated. Therefore, in order to find out accurately the savings achieved, one must make a new heat balance.

In spite of these complexities, the control of excess air is probably the single most important item in energy conservation in furnaces. The determination of excess air by means of a flue gas analysis is essential, in any event, to the calculation of stack losses and the setting up of a heat balance.

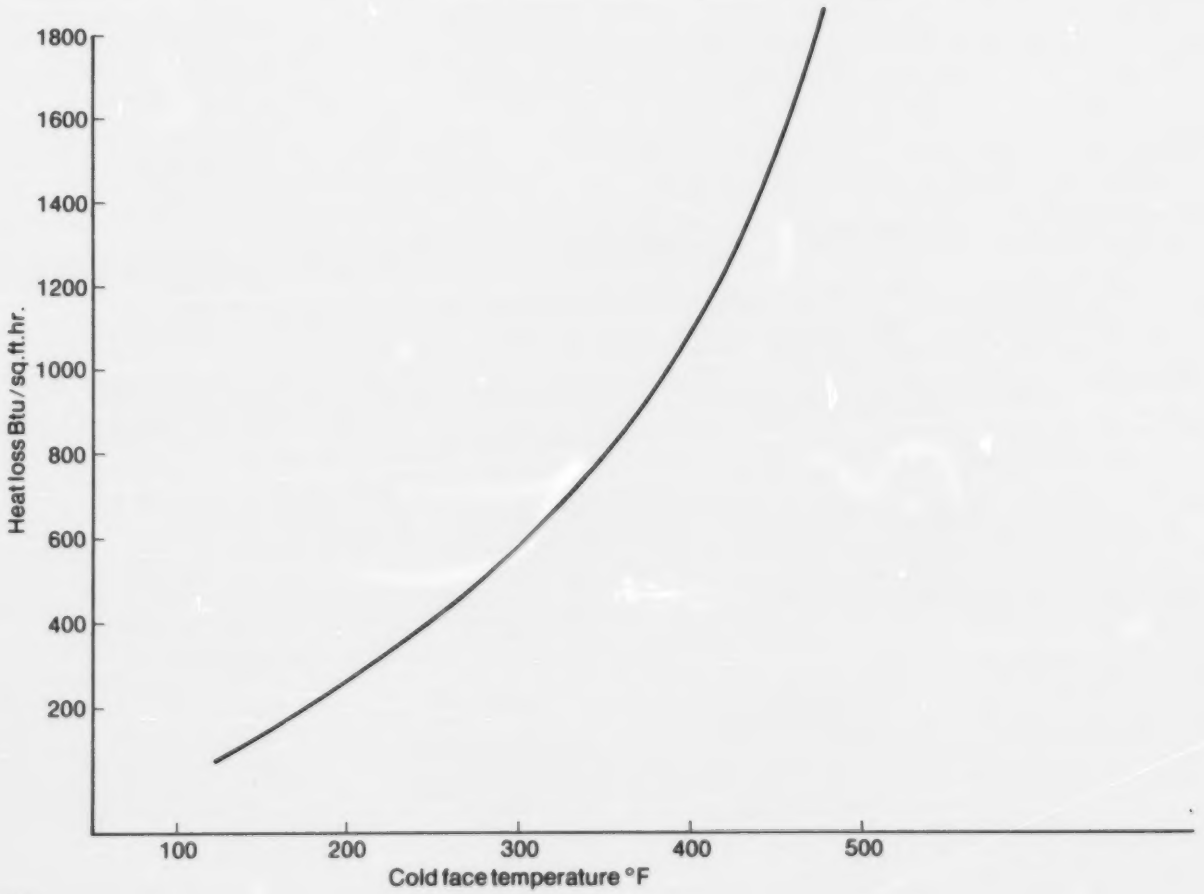
Recover Waste Heat.

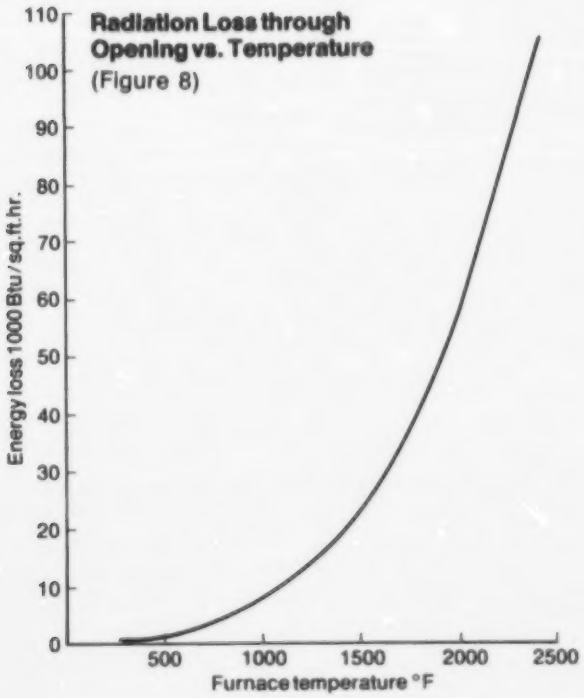
An industrial furnace, kiln, or oven almost inevitably exhausts gases at some temperature above the ambient, and hence contain useful energy which can be recovered. The uses to which recovered energy can be put are numerous. If the gas is at a high temperature, say 816°C or higher, it can be used to generate steam and perform mechanical work or to generate electricity. Lower temperature gas streams have less value, but can be useful and save cost in such applications as drying and preheating incoming products, in heating water, or in space heating. If the stream is only a few degrees above the ambient temperature, it may still contain energy, but it may well be impossible to recover it economically.

If recoverable energy is not available on a regularly scheduled or continuous basis, it is usually best to try to return it to the same system that produced it. An example is the use of stack gas heat from an intermittently operated furnace to preheat the combustion air for the same furnace. In this application, waste heat still exists at a reasonably high temperature, and could be useful for space heating or for drying even if it had to be supplemented during furnace shut down by an auxiliary heater.

The "Process Design" book in this series contains much information on energy recovery techniques. Case histories of particular applications are found in a number of the booklets in this series (see the index in Booklet 1 for a complete list).

Heat Loss from Furnace Walls vs. Outside Wall Temperature (Figure 7)





Radiation Loss through Opening vs. Temperature
(Figure 8)

Insulation.

Furnace insulation that is inadequate or in poor condition can waste large amounts of energy, and usually in a form that is not readily recoverable. In fact, in one recorded case 20% of the fuel energy fired was still being lost through insulation after the obvious steps to conserve energy had been taken.

For an indication of the importance of the losses by measuring the temperature of the outside of furnace walls and roof. A temperature of 80°-66°C indicates that the losses are in the reasonable range; a temperature of 260°C or higher means that the losses are probably quite large. An estimate of the energy loss per square foot per hour, as a function of outside wall temperature, is shown in the chart.

For a large installation, an infrared thermographic survey will measure accurately the temperature of large and complex areas. It will also serve to highlight hot spots, even quite small ones, caused by locally damaged insulation.

When installing new insulation or when retrofitting existing equipment, one should give serious consideration to ceramic fiber blankets instead of conventional fire brick. This material offers several distinct advantages:

- It has only one-third to one-half the heat conductivity of fire brick, and may be installed in correspondingly thinner layers for a given heat loss.
- It has a heat storage of about one-tenth that of an equivalent layer of insulating brick. This feature saves both energy and time in start-up, or in reheating during a batch cycling operation.
- It is immune to failures by spalling or cracking due to rapid heating and cooling.
- Its light weight makes it possible to install it without major rebuilding of a furnace.

It does, however, have some disadvantages:

- Since it is very low in physical strength, it cannot be installed on furnace floors or in other areas where it would be subjected to mechanical abrasion.
- Since its insulating properties depend on its high porosity, its use should be questioned in any service where the pores might be plugged up by condensing fumes or by particulate matter.
- It is intended for installation on the hot side of furnace walls or roofs. A blanket of fiber on the cold side of an existing furnace wall may cause some of the interior layers of brick to heat beyond their useful service temperature.

Openings and Leaks.

The mechanisms by which energy is wasted through open ports in a furnace or accidental leaks in the system can be classified as radiation losses, convective losses through the opening (exfiltration), or both.

Radiation is, of course, a line of sight phenomenon; if we can see the hot inside of the furnace, heat is being lost by radiation. The amount of heat loss is a linear function of the area of the opening and is proportional to the fourth power of the absolute temperature.

As a simplified example, a slot opening 6" high by 8' long in a 1204°C forging furnace will lose heat by radiation at a rate of 79,000 x (0.5 x 8) = 316,000 Btu/hr. This is in addition to any loss resulting from gases flowing through the opening.

Outward gas flow through a port or leak is generally not a major source of energy loss. If the leak is merely hot completely burned gas from

the furnace, it represents a small amount of exhaust gas which otherwise would have been wasted up the stack. If the outward leak results in long flames outside the furnace, it will represent a significant heat loss to the process. This could be eliminated by fixing the leak or optimizing the flame shape.

The infiltration of cold air into the furnace can, on the other hand, represent a serious energy loss. Every pound of excess cold air leaking into a 1204°C furnace represents a waste of 510 Btu. This infiltration commonly occurs because, in the absence of a well adjusted flue damper, there tends to be a slight vacuum near the bottom of the combustion chamber. Due to the "chimney effect", the pressure will be lowest at the furnace floor and will gradually rise to the local barometric pressure at the point where the stack exhausts to the atmosphere. The pressure difference, hence the volume of the air infiltrated and the amount of energy lost, depends on the furnace temperature, the height of the flue gas exit above the furnace floor, and the size of the opening through which cold air is entering.

The following table illustrates the relationship among these variables:

Heat Loss Due to Air Infiltration
Btu per hour per sq. in. of opening

Temp.	Height — Furnace Floor to Stack Exhaust					
°C	6′	8′	10′	12′	16′	20′
409	3600	4000	4800	5200	6100	6900
614	5500	6900	7500	8100	9800	11000
836	8200	10200	11200	12700	15200	17500
1040	10510	13200	14700	16500	18500	21300
1244	13500	16200	18100	20500	23200	25900

Thus, a slot opening 8 feet long by 6 inches high in a 1204°C forging furnace, with the stack exhaust located 12 feet above the furnace floor, would have the following heat loss due to air infiltration:

18,500 Btu/hr. sq. in. × (8 x 0.5) sq. ft. × 144 sq. in/sq. ft. = 10,600,000 Btu/hr.

This much energy is equivalent to 76 gal. (U.S.) of #2 fuel oil per hour. To prevent such an excessive loss, a damper or other constriction should be installed in the exhaust stack in order to increase the pressure in the combustion chamber to atmospheric or slightly higher. A frequent recommendation, even with openings or leaks much smaller than that described above, is to install an automatically controlled damper to maintain a positive pressure of 0.01 to 0.05 inches of water. Thus, if leaks do occur, they will be small outward leaks and will waste far less energy than cold air infiltration.

Shut Down Idle Equipment.

When heating equipment is out of service, either due to scheduled shut downs or to interruptions in production, energy can almost always be saved by allowing the equipment to cool down and reheating it later. If the shut-down time is short, it may be best to permit the equipment to cool to some intermediate temperature, to idle at this reduced temperature for a period, and then reheat to the operating temperature.

Unfortunately, there seems to be no good general law or rule-of-thumb as to when to shut down, when to idle at lowered temperature, and when to hold at operating temperature. The best decision depends not only on the projected down time, but most importantly on the characteristics of the specific piece of equipment under consideration. To reach a decision which will save the most energy, several bits of information are needed. They are:

1. The time for the equipment to cool, with burners off, to room temperature as well as to several intermediate temperatures.
2. The rate of fuel flow required to idle at operating temperatures and at each of the intermediate temperatures.
3. The time required to reheat from room temperature and from each of the intermediate points.
4. The total fuel required to reheat from each of the above temperatures.
5. The maximum rate of temperature change that will not result in equipment damage.

With this information, and a projected down time schedule, the cycle which uses the least fuel is easily determined.

In some cases the desired shut down and reheat cycle may incur some additional labour costs; in others, product or equipment may be damaged by excessive heating or cooling rates. These costs must, of course, be balanced against the savings in the cost of energy.

Schedule for Full Load Operations.

It is generally accepted that it is more efficient to operate heating equipment at its full design load rather than at some lower production rate. It is simple to translate this conventional wisdom to actual fuel usage and costs.

As an example, consider a continuous brazing furnace, fired at the rate of 5×10^6 Btu per hour, and a full load capacity of 100 units of product per hour. A heat balance shows that 1×10^6 Btu actually heats the product (10,000 Btu / unit), while the other 4×10^6 Btu goes to stack and other losses. This is a reasonably high energy efficiency for a heating treating operation.

If the required production rate is reduced to one-third of the furnace capacity, there are two general alternatives:

1. The furnace can be operated at 100 units per hour, but only operated every third day or third week. The fuel usage will be 5×10^6 Btu / hr., or 50,000 per unit of product, disregarding the energy required to reheat the furnace to working temperature.
2. The furnace can be operated every day with product fed at only 33 units per hour. Under these conditions, the furnace will still waste energy at the rate of 4 MMBtu / hr., and will deliver 330,000 Btu / hr. to the product. Total fuel usage will be 4,330,000 Btu / hr., or $\frac{4,330,000}{33} = 131,000$ Btu per unit.

The second alternative is probably the more convenient schedule in that it minimizes the problems of material handling, of storage space for a larger work-in-process inventory, and of poor worker morale that sometimes (not always!) results from frequent changes in job assignments. It also increases by 81,000 Btu the energy used per unit of product.

Alternative one, in spite of its scheduling inconvenience, is very attractive.

In some cases it may be desirable to increase the throughput of an existing furnace. If, in the previous example, it was decided to increase the production rate from 100 units per hour to 120 units it could conceivably be accomplished by speeding up the conveyor mechanism by 20%. Since, this would reduce the dwell time of the product in the furnace, it might be necessary to increase the heat transfer rate by raising the temperature of the furnace atmosphere, thus increasing the fuel consumption per hour. The higher temperature in the furnace would result in increases in stack loss and in the loss through furnace walls and roof. The increased volume of hot gas flowing would cause greater turbulence, which would increase both the heat transfer to the product and the loss through the walls.

The result of all of these conflicting changes is very difficult to estimate; it might be that the scheme is possible, but only at a sacrifice in efficiency, i.e., an increase in fuel used per unit of product. If the conveyor already has a variable speed drive, it might be possible to try the proposal and generate a new heat balance. If not, a discussion with the furnace manufacturer or a competent consultant is suggested before expensive and irreversible changes are made.

Minimize Energy Loss During Cycling.

When a batch furnace is opened to remove one load and put in another, it is obvious that large amounts of energy are lost through radiation and cold air infiltration as discussed earlier. The amount of this loss can be measured by a rather simple experiment:

1. Open the hot furnace and remove a batch of product as usual.
2. Reload any jigs or fixtures that are normally used — do not load any product. During these two steps, the furnace should be open for the length of time that is normal in production.
3. Close the furnace, and reheat to operating temperature.

The amount of fuel used during these steps is a direct measure of the energy lost due to cycling.

The major source of the wasted energy is the stored heat or sensible heat, in the hot furnace walls, floor, and roof. The loss mechanisms are both radiation and cold air infiltration through the open door(s). The normal heat loss by conduction through the furnace walls is usually small when compared to this "open door" loss. Another souce of wasted heat, usually less important, is the sensible heat of any jigs, fixtures, or carriers which must be heated and cooled during each cycle. These facts point to several techniques of conserving energy.

- Since the heat flow through open doors is a function of time, energy is saved by keeping the open-door time as short as possible. If, for example, one must wait 10 minutes for arrival

of the next batch of product to be treated, shut the door during the waiting period.

- Supporting jigs and fixtures should be designed for the minimum heat capacity. In general, this means designing to the minimum mass. Note that in terms of heat capacity per pound, most metals store only half as much heat as ceramics.
- The most important method of saving energy in a furnace which must be cycled is to use an insulating material which has a very low heat capacity per unit volume, such as ceramic fiber. The following analysis is based on data furnished by an insulation manufacturer.

A wall of insulating fire brick, designed for furnace temperature of 1093°C and a cold face at 94°C, would be about 12" thick and would store 12,600 Btu/sq. ft. of sensible heat. In a furnace of 8' x 6' x 5' inside dimensions, this amounts to a total storage of 2,970,000 Btu. If the furnace cooled to 927°C during a batch change, the storage would be reduced to 2,510,000 Btu, or the energy loss would be 460,000 Btu.

Ceramic fiber insulation on the other hand, would be only 4.7" thick and would store only 680 Btu/sq. ft. The total stored heat would be 733,000 Btu most of it in the brick floor, and the loss in cooling to 927°C would be only 114,000 Btu. Assuming a stack loss of 45% during the re-heat period, the fuel saving due to ceramic fiber insulation is

$$\frac{(46{,}000-114{,}000)\ \text{Btu}}{(1-0.45) \times 180{,}000\ \text{Btu/gal}} = 4.5\ \text{gal. of fuel oil}$$

If the temperature dropped to 780°C during cycling, the saving would be 7.2 gal. of oil.

For heating up from room temperature, the firebrick insulation would require 38.5 gal. of oil; the ceramic fiber design only 9.5 gal.

Miscellaneous Energy Conservation Opportunities.

There are many practices and procedures for furnaces, kilns and ovens that waste energy that often go unnoticed. This listing is not exhaustive, but covers some of the more important points:

- Over-specification by the parts designer is sometimes due to an early desire for a large factor of safety, to a reluctance to change something that is working, or to a lack of appreciation of the present cost of energy and its probably future increase. Examples include such things as a carburized case of 0.040 when 0.020 is adequate, or a drying and baking schedule on a painted part of one hour when 20 minutes is long enough. Design engineers will usually welcome cost saving suggestions, particularly if the credit is shared.
- Production people are guilty of a similar energy waste when they extend an annealing cycle 2 hours longer than is necessary or when they start heating up a cold furnace earlier than need be because it's more convenient. Education and an energy conscious approach are needed.
- Protective gas atmospheres which are allowed to flow at a greater rate than is essential are wasting energy, both in the mass of gas which must be heated in the furnace, and in the fuel value of the protective gas used.
- Massive jigs, carriers, or fixtures which must be heated and cooled with each batch, or with each trip through a continuous furnace, constitute a built-in energy waste. Such jigs should be as low in weight as possible; in some cases they can be completely eliminated.
- Water cooled rails, supports, door parts, etc., waste energy with every gallon of warm water that is sent to the drain. They can often be replaced with parts made of heat resistant alloys or ceramics, or the heat in the hot water may be recoverable.
- Scaling problems have sometimes been controlled by using expensive alloys when the same result might have been achieved by adjusting the excess air to keep the furnace atmosphere down to 1 or 2% oxygen. The latter course saves energy, both in the heat treating furnace and in the alloy preparation.

Continuous Efficiency Monitoring.

The most efficient of furnaces can drift from its optimum adjustments unless it is monitored on a regular basis.

The most important monitoring instrument is a fuel usage meter, preferably one for each major piece of fuel using equipment, read at least weekly and preferably at the beginning and end of each shift. A graph or a tabulation of fuel consumption per unit of production will soon show changes in equipment or in production practices which affect energy efficiency adversely. Just as important, such monitoring will measure the efficiency of an energy conservation project.

Fuel monitoring is, or course, the bottom line measurement for energy efficiency, but it has its limitations. It can detect some of the causes of possible energy waste, particularly those that have to do with scheduling changes such as excessive idling, changes in batch size, changes in product design, etc. In the case of other possible causes for energy waste, such as a change in the amount of combustion air, fuel monitoring alone will disclose a change, but will give no clues as to the cause. For this reason, some additional monitoring is desirable.

A complete flue gas analysis is also a very useful tool for checking furnace efficiency and is suggested at regular intervals. Possible schedules might be set up for checking monthly, or even more frequently.

Continuous flue gas analyzers (oxygen) are recommended for any major combustion use. As well as being permanently recorded, readings should be noted hourly — along with other important parameters, particularly exit temperature. Any changes in readings should be examined and its cause (such as changes in excess air or infiltration, or even fuel quality) determined. The cost of an analyzer can be justified by the speed with which it can indicate trouble and save both fuel and production material.

An instrument for measuring flue gas temperature is often not installed, since it can be assumed that this temperature depends directly on the control temperature in the furnace. If, however, a recuperator or other waste heat recovery device is put in, temperature at the flue gas outlet from this heat exchanger should be measured. A change in this temperature, if not accompanied by a change in furnace temperature, would indicate that the heat exchanger is not operating properly and needs maintenance or repair.

No monitoring instrument can replace the need for a good preventative maintenance programme. The reverse is also true; the best of maintenance skills does not do the same job as instrumentation. To hold to a high level of energy management, both maintenance and monitoring are needed.

Methods of measurement for heat balances

Previously, it was pointed out that measurements of such factors as fuel usage rate, temperatures, flue gas analysis, etc., are necessary for estimating a heat balance and overall efficiency of a furnace, kiln or oven. A few basic suggestions on measurement are in order.

Measuring Fuel Consumption.

The ideal instrument for measuring the flow of gas or oil to a furnace is a positive displacement totalizing meter, of the type used by fuel vendors. If such a meter is read once an hour, or even once a shift, the hourly fuel rate is readily calculated for the furnace on which it is installed. It can easily be moved from one furnace to another, if appropriate pipe fittings and valves are installed in the fuel line to each furnace.

Flow indicators, such as orifice plate or a rotameter, are usually less expensive and may be adequate for measuring a flow rate that is steady over long periods of time. They are not satisfactory when the temperature control system is one which makes frequent large changes in the amount of fuel supplied. In such cases, a totalizing meter is essential. Flow indicators can be useful to assure that proper fuel distribution exists among the individual burners of a multi-burner installation. This requires, of course, an indicator installed on each individual burner.

Meters of any type should be sized for the job. For example, if a furnace uses 100 cfh of gas, a suitable meter should indicate amounts as small as 1 cubic foot. If, on the other hand, the usage is 10,000 cfh, a minimum indication of 100 cf is adequate.

Measuring Energy Input — Electric Furnaces.

Here the instantaneous flow rate of electrical energy can conveniently be measured with a clamp-on ammeter. This instrument will measure the current demand in amperes if *one* of the wires to the furnace is surrounded by the spring loaded C-clamp which is part of the instrument. The flow rate (power) in watts is simply amperes times the applied voltage, or if multiple heating elements are wired into a

3-phase network it is amperes times volts times the square root of three (1.732).

If the temperature control system is of the full on-off variety, you can measure energy by wiring an electric clock across the heater terminals to indicate the total turned-on time. For example, if after 8 hours of elapsed time the clock indicates 5.5 hours, and the heaters draw 15 kilowatts, the average energy usage rate is 15 Kw $\times \frac{5.5h}{8h} = 10.3$ Kw.

If the temperature is controlled by a throttling device, such as variable inductance transformers or silicon controlled rectifiers (SCR's) one must use a recording kilowatt hour meter of the type used by the electric utility companies.

Measuring Temperatures.

For the temperature range of concern in this handbook, a thermocouple is by far the most convenient and satisfactory device; thermometers, of either the bi-metallic or liquid filled variety, may sometimes be less expensive; however, they are limited to temperatures below about 427°C, and can be inconvenient to read if the required location of the measurement is in a spot that is difficult to reach.

When the temperature to be measured is that of furnace flue gas, the temperature should be measured as near as possible to the point at which the gases leave the combustion chamber. If the measurement is made after the gas has been cooled, either by wall losses from duct work or by the infiltration of cold air, the resulting heat balance will be erroneous. If the flue gas is fed from the combustion chamber to waste heat recovery gear, such a recuperator, a heat exchanger, or a waste heat boiler, temperature measurements, should be made both at the combustion chamber exit and at the exit from the heat recovery device. Both measurements are needed in order to be assured that the heat exchanger is continuing to operate properly.

Analyzing Flue Gas

As covered in the section of this booklet on boilers, the Orsat analyzer has long been considered the standard instrument for a flue gas analysis. It analyzes separately for the following gases, by volume.

- Carbon dioxide — an indicator of the amount of excess air.
- Carbon monoxide — in amounts more than about 0.1% is an indicator of incomplete combustion.
- Oxygen — is a general indicator of the amount of excess air — regardless of the fuel used.
- Nitrogen — is not analyzed directly, but is assumed to be the remainder of the sample.

Water is condensed during the sample preparation. Its amount in the hot gas can be estimated from the amount of excess air and a knowledge of the type of fuel used.

A simpler, less costly device than the Orsat measures only CO_2 by chemical absorption and is commonly used by servicemen in adjusting domestic furnaces. It should be used as a guide but not considered absolutely accurate.

Several electronic instruments can be installed to continuously monitor flue gas. Infrared units to measure carbon dioxide or paramanetic or zirconium oxide units to measure oxygen yield accurate and permanent records of changes in combustion conditions. Where fuel type or composition may change, the oxygen type of analyzer is preferable to the CO_2 unit.

For controlling burner performance, samples should be taken as close to the burner as possible if infiltration is believed to occur. Further measurements downstream can show leaky settings, where heat loss occurs.

Measuring Gas Flows at Low Pressures.

If the amount of excess air in a furnace or oven must be more than about 200%, the use of an Orsat analysis to calculate mass flow rate and stack loss becomes very inaccurate. One must resort, therefore, to direct measurement of the gas flows either at the air intake, in the stack, or some other convenient point in the system.

Flow meters all cause some slight drop in pressure of the flowing fluid and are not suitable for use in the combustion system, where pressure is typically only 1 to 4 inches of water. The choice of instruments, then, is rather limited.

The pitot tube actually consists of two tubes, one with an opening facing into the flow. The difference in pressure between the two tubes is an indication of gas velocity. Pitot tubes may be used in ducts 4" in diameter or larger, over a quite wide range of gas velocities, and at temperatures limited only by the material for tube construction. For best accuracy, there should be 10 diameters or more of straight duct before and after the pitot tube.

A hot wire anemometer indicates gas velocity by measuring the cooling effect of a gas stream on an electrically heated wire. They are available as either fixed or portable instruments. They are limited in the temperature at which they can operate; 120°C is a normal upper limitation.

Mechanical anemometers utilize a fan or a turbine whose rotational speed is a function of the velocity of the driving fluid. Depending on application, e.g., hand held for room air velocity measurement or models for permanent installation in a pipeline, their cost and complexity vary widely. They are, for mechanical reasons, usually confined to temperature ranges below about 94°C.

In general, all of these devices are subject to major errors if they are allowed to collect gummy materials or particulate matter. Under such conditions one must clean the instruments quite frequently, or depend on the Orsat analysis and calculate the gas flow rate.

Different types of Furnaces, Kilns, and Ovens

The principles of obtaining the measurements and performing the calculations for a heat balance are exactly the same for each type of industrial heating equipment. They are, of course, to identify and to measure or estimate all the quantities of energy entering and leaving the equipment. In this sense, the job is the same whether the equipment is called an electric box hardening furnace, a bell furnace, a brick kiln, or a continuous bakery oven. There are nonetheless detailed differences in the best approach to the job, depending on the specific type of equipment.

Direct fired furnaces.

Direct fired furnaces are those in which the products of combustion (the flue gas) come into direct contact with the product being heated. This category may be subdivided into batch and continuous furnaces.

Batch direct fired furnaces include the following commercial types.

Box furnaces.

Car bottom furnaces.

Pit furnaces.

Bell furnaces.

Rotary retort (some).

These furnaces may be further classified according to their intended use, such as brazing, drawing, hardening, forging, etc.

The example in an earlier section illustrates a heat balance on this type of furnace. Specific items to watch for — in addition to fuel air ratio, adequate insulation, and waste heat recovery — are listed below:

- Frequent opening and closing of the furnace often results in leaks around the gaskets or seals, and energy losses by cold air infiltration. This can be particularly important in the seals around the edges of a car bottom furnace. Regular inspection and maintenance is called for.

- Air infiltration through unavoidable leaks can be prevented, or minimized, by installing an automatically controlled flue damper to maintain a balanced pressure in the furnace chamber.

- An obvious source of energy loss with a batch furnace is the heat which escapes during the unloading and reloading period between batches. This loss may be measured by metering the fuel flow from the time the door is opened for unloading until it is closed on the new load and the next cycle started. While this loss was not treated in detail in the heat balance described earlier, it obviously must be considered in calculating overall fuel usage per unit of product.

- A single batch cycle will, of course, use less energy if the furnace walls are relatively hot when the cycle starts; hence, the door open time between batches should be held to the minimum.

Another type, the continuous direct fired furnace, is one in which product is fed into and removed from the furnace in either a continuous or intermittent fashion, i.e. there is no distinct batch.

Commercial designations include:
Belt furnaces.
Roller hearth furnaces.
Rotary hearth.
Shaker hearth
Slot (forging) furnaces.
Pusher furnaces.
Rotary retorts (some).
Rotary kilns, and others.

A heat balance for a continuous furnace is essentially the same as a batch furnace, however, there are some special considerations involved:

- Since there is no batch cycle time, measurements and calculations should be made on the basis of some specific time interval such as an hour or a shift. Ideally, heat balances should be made both at idling (no load) conditions, and at design (full load). Fuel use at partial loads can be estimated from these data.

- Since access ports for the charging and removal of product are open either all or most of the time, energy loss because of the openings is more important than in a batch furnace. A slight positive pressure in the furnace is recommended.

- Losses by radiation through open ports can be large, and might well be considered as a separate energy loss in the heat balance. It is obvious that such openings should be as small as is practical.

- In some continuous furnaces, the material handling gear (belt, rollers, etc.) is all within the hot zone. In others, however, a belt may leave the hot zone and return at room temperature. In such cases, the energy required to reheat the belt should be considered as a loss (energy output) in calculating the heat balance.

Indirect fired furnaces.

These are furnaces in which the combustion gases do not come into contact with the product. This may be merely to protect the product from the local over heating; it is more frequent to permit careful chemical control of the furnace atmosphere (e.g. oxidizing, reducing, neutral, carburizing, etc.).

These furnaces may be batch or continuous in operation; may be any of the mechanical designs listed under direct fired furnaces (box, pit, bell, roller hearth, etc.) and can be further broken down into:

- Muffle furnaces.
- (Controlled) atmosphere furnaces.
- Radiant tube furnaces.
- Carburizing furnaces.
- Carbonitriding furnaces.
- Salt pots.

Those various methods of categorizing can give rise to such labels as a "box type, radiant tube, controlled atmosphere, hardening furnace."

An indirectly fired furnace with atmospheric air in contact with the product can be treated in almost exactly the same way as an equivalent direct fired furnace from the point of view of a heat balance. There are two minor exceptions.

- If outside air is deliberately drawn through the product chamber, e.g. to cool the product before discharge from the furnace, the volume and the exit temperature of this air must be measured, and its heat content added to the output side of the heat balance.

- If air is not circulated through the product chamber, i.e. if the chamber is closed as well as possible, there will not be any tendency towards air infiltration as is the case in direct firing. It is unnecessary and undesirable to make any efforts to hold a positive pressure in the product chamber.

In a controlled atmosphere furnace the product chamber is flushed free of air with some special gas, and gas continues to flow during the firing cycle to maintain a slight positive pressure. The energy flows due this controlled atmosphere should be accounted for.

In calculating the heat balance one should

consider the gas generator as part of a single system along with the furnace itself, and treat the energy used by the generator per hour or per cycle as one of the energy inputs. Since only a very small percentage of the atmosphere will actually combine with the product, this same amount of energy should appear as a waste heat output.

The following list, indicates the method of calculating the heat content of different types of furnace atmospheres.

- For exothermic generator gas, the energy content should be considered as the heating value of the fuel furnished to the generator.
- For endothermic generator gas, the energy content is the fuel value of the gas charged, including that which is used for external heating of the generator tubes.
- Dissociated ammonia has a fuel value of 16,000 Btu/lb (490 Btu/cf), plus the energy used for external heating of the generator tubes.
- If any of the above gases are conditioned by the removal of water vapor and/or carbon dioxide, the energy for this conditioning must be added as part of the system input.
- Pure hydrogen has a heating value of 61,100 Btu/lb, or 325 Btu/cf.
- Nitrogen, liquid or in pressure tanks, has no heating value.
- Propane, used in preparing enriched gas, has a heating value of 22,000 Btu/lb., 91,000 Btu/gal, or 2500 Btu/cf.

The need to meter gas to an atmosphere generator is implied by the preceding. If a central generator is used to furnish the atmosphere gas for a group of furnaces, it may be adequate to meter material to the generator and estimate its allocation to the individual furnaces.

Special types of indirect fired furnaces.

a. Salt pots.

A salt pot — a fused salt bath — is a special type of a batch indirectly fired controlled atmosphere furnace. In calculating a heat balance, it may be treated like a direct fired batch furnace with, usually, a quite short cycle time. The single exception is the need to determine the amount of replacement salt charged per cycle, to calculate the energy needed to melt the salt and raise it to operating temperature, and to list this energy as a heat output.

The radiation loss from the open surface of a salt pot may be significant. It should be estimated and listed as an output in the heat balance.

b. Pack carburizing.

Pack, or box, carburizing is technically an indirect fired controlled atmosphere operation, which is usually performed in a batch type direct fired furnace. The heat required to heat up the carburizing box and all of its contents is part of the output in a heat balance. The fuel value of the carburizing material, charcoal for example, is added to the input side of the heat balance. If a portion of the charcoal is recovered for re-use, one need only consider the new charcoal added for each batch. To conserve energy, the tare weight of the box per pound of product, as well as the amount of carburizing material used, should be as low as is practicable.

c. Recirculating furnaces.

Recirculating fans or blowers act to mix or stir the furnace atmosphere. They promote a more uniform temperature, and at lower temperatures can increase the rate of heat transfer to the product. Since recirculation systems are designed to neither add or subtract energy from the furnaces, they can be generally ignored in calculating a heat balance. If portions of the recirculating system are outside of the heated zone, they can contribute to the energy losses due to radiation and convection. Outside ducts and fan housings should be well insulated.

Dryers.

Dryers can be defined as heating equipment, with the purpose of driving off a volatile material such as water or an organic solvent. They may be either batch or continuous in operation. The commercial name of a dryer will usually refer to the product being treated:
Paint drying oven.
Ceramic dryer.
Lumber kiln.
Continuous bakery oven.
Rotary retort parts dryer.
etc.

Dryers are usually operated at low temperature (66°C-260°C). However, in spite of this, heat

losses by radiation and convection from walls and ceiling can be very important, since the wall and ceiling areas tend to be rather large, and cycle times may be lengthy.

In addition, dryers are often operated with rather large quantities of excess air (200-1000%), in order to promote rapid drying and to prevent forming an explosive atmosphere if the solvent is combustible. If the excess air is above about 200%, a flue gas analysis becomes very inaccurate and direct measurement of air or flue gas flow rate must be used in order to calculate the stack loss. Obviously, the amount of excess air should be no greater than is required by the demands of the process.

Some further considerations with dryers:

- If the solvent being evaporated is combustible, the fuel value (heat of combustion) must be added to the input of the heat balance.
- Air pollution regulations require that hydrocarbons such as paint solvents be removed before any gas stream is exhausted to the atmosphere. This can be done by a variety of means, the most common one being to burn more fuel with the stack gas and raise its temperature to about 871°C. Whatever the method, this clean up operation must be considered as an integral part of the system, and all the energy added at this point is an energy input to the heat balance.
- Drying systems commonly have very high stack losses because of the necessity of high percentages of excess air and the need to incinerate hydrocarbons vapors. Special attention should be given to the means of recovering this waste heat and if possible returning it to the system.
- Dryers are sometimes part of a more complex system. For example, in a continuous brick kiln-dryer combination there can be different zones: to dry out water, to increase the temperature slowly to the firing level, to fire the bricks, and to cool at a controlled rate. Bricks may be dried by hot air recovered from the cooling zone of the kiln.

To calculate a heat balance, the complex should be treated as a single system and only the energy and material flows which enter and leave it considered. If necessary, energy balances for a single part of the system such as the drying zone can then be estimated.

Electric furnaces.

Any of the types of furnaces, kilns, or ovens described up until now can be heated electrically instead of by directly burning fossil fuels. However, there are a few special items to consider in making a heat balance.

- Since there are no fuel combustion products, there is no stack loss in the usual sense. If the application is to a dryer or to a controlled atmosphere furnace, one must, of course, consider the energy flows associated with the drying air or with the special furnace atmosphere.
- A heat balance on an electric furnace, using a conversion factor of 3412 Btu/Kwh, will normally show a lower heat input than is required by an equivalent furnace fired by gas or oil. The high cost of electricity per Btu will frequently, however, out-weigh the apparent saving.
- To compare a gas or oil fired furnace with its electrical equivalent on the basis of fossil fuel burned instead of cost, a kilowatt hour should be valued at 10-12,000 Btu. This is the value of the fuel burned by a generating station to produce one kilowatt hour of electricity worth 3,412 Btu for furnace heating. The power plant loss is reflected, of course, in the cost of electricity.

Financial considerations.

The previous sections contain some suggestions for energy saving which will require the investment of capital dollars in order to achieve savings. In some cases, the savings per year may be so large, and the capital cost so small, that the desirability of the project is obvious. In other cases, a more detailed analysis is needed.

The Guidebook/Index discusses two of a number of procedures for making a financial analysis of your cost saving opportunities. An important factor in your analysis is the amount you are paying for your energy.

The reason for determining energy costs is to allow you to make valid analysis of the actions you might need to take to save energy and money. The cost varies widely with the fuel source used.

Industrial boilers

Among combustion devices, the industrial boiler is one of the largest consumers of energy. In fact, as a rough rule of thumb, 40 percent of total energy consumed in Canada is used by the industrial sector. Of this, roughly, 11 percent is used for direct heating — a full 16 percent goes into the production of steam. Obviously, improvements in boiler performance offer a real opportunity to reduce a significant proportion of fuel consumed on a national basis. But perhaps of greater interest in the short term, improvements in boiler performance generally spell substantial savings in operating costs for Canadian industry.

Getting Peak Performance.

The fundamental purpose of any industrial heating system is to convert the energy contained in the chemical bonds of the fuel into heat, and to transfer this heat into a working fluid such as steam, oil or air. The energy content of fuel is defined by its *heating value,* the number of British Thermal Units (Btu's) contained per unit weight or volume of the fuel. Combustion engineers generally make a distinction between the so-called "lower heating value" (LHV) and the "higher heating value" (HHV) of the fuel, the difference being the small amount of heat associated with the condensation of moisture in the flue gas. In boiler work, the HHV is the commonly used figure. Some typical HHV's for commonly used fuels are:

Natural Gas — 1,000 Btu/cu. ft.

Fuel Oil
No. 2 — 166,000 Btu/gal.
No. 6 — 180,000 Btu/gal.

Coal
Bituminous — 14,000 Btu/lb.
Sub-bituminous — 10,500 Btu/lb.
Lignite — 7,500 Btu/lb.

Again, the lowest grade fuel possible should be used whenever possible, to conserve premium fuel for those applications where they can be used most efficiently.

In the furnace, fuel is mixed with air and ignited, causing carbon, hydrogen, and sulfur in the fuel to oxidize rapidly and liberate chemical bonding energy. A precise amount of air is required to insure that there will be an oxygen molecule available for every combustible molecule. This precise amount is known as the *100% theoretical air, theoretical air or stoichiometric air.* If less than the theoretically required air is introduced into the furnace, there will be insufficient oxygen available, and some of the combustible material will go up the stack, paid for but unused. If more than the theoretical air is supplied (which is almost always done in actual practice, for reasons which will be discussed later) the furnace is said to be operating with *excess air,* usually expressed as a percentage of theoretical air. For example, a gas-fired package boiler may operate with about 35% excess air, or 1.35 times the theoretically required amount.

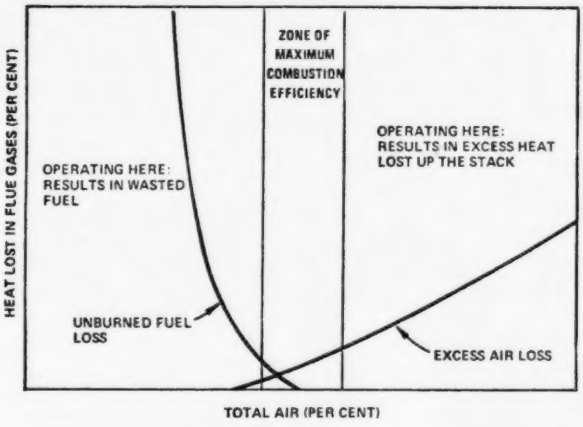
The mixture of gases which results from combustion of the fuel, consisting primarily of carbon dioxide, water vapor, nitrogen, and oxygen, makes up the *flue gas.* While some of the heat produced by the combustion reaction is transferred directly to the steam or process fluid by the radiation from the luminous flame in the furnace, a substantial amount of heat remains in the flue gas as it flows through the boiler. As the hot gas rises through the stack, heat is further extracted from it as it passes over banks of tubes placed in the gas path. These tube banks, known as *transfer* heater sections, are the important type to consider when retrofitting an existing boiler with heat recovery equipment.

Ultimately, of course, the objective is to get the heat into a working fluid which can be used in the process. The degree of success toward this goal is measured as *boiler (or heater) efficiency.* Boiler efficiency is calculated by dividing the quantity of heat transferred into the working fluid by the chemical heat content of the fuel entering the system. Boiler efficiency is the number we are most interested in, because it represents useful energy produced compared to theoretically available energy. In the sections which follow, this will be referred to simply as "boiler efficiency", although it will be understood that this could apply equally to process heaters in which the working fluid is other than water.

Parameters Affecting Boiler Performance.

Numerous operating and design variables have a substantial effect on boiler efficiency. It is important that each of these influences be

Effect of Combustion Air on Boiler Performance (Figure 9)


HEAT LOST IN FLUE GASES (PER CENT)
ZONE OF MAXIMUM COMBUSTION EFFICIENCY
OPERATING HERE: RESULTS IN WASTED FUEL
OPERATING HERE: RESULTS IN EXCESS HEAT LOST UP THE STACK
UNBURNED FUEL LOSS
EXCESS AIR LOSS
TOTAL AIR (PER CENT)

understood, so that alternative measures which may be taken to improve the efficiency may be considered.

Fuel Characteristics: The properties of the fuel used in the boiler or heater exert a major influence on efficiency. To achieve proper combustion, the fuel must be well mixed with the combustion air. Mixing is a complicated phenomenon, particularly when liquid or solid fuels are used. When fuel oil is burned, it must be atomized to produce tiny droplets with a large surface area exposed to the air. The density, viscosity, and surface tension of the oil are all important determinants in the atomization and mixing process. Since these factors are greatly affected by temperature, it is necessary to maintain the fuel at the temperature for which the burner was designed. This is especially important when using heavy residual fuels (e.g., No. 4 or No. 6 fuel oil).

Another important property is the fuel heating value. This property is determined by the fuel's chemical composition and its water content.

Excess Air: The amount of excess air used in combustion is a crucial variable affecting boiler efficiency. The chart shows why. As pointed out earlier, a certain minimum amount of air is required to provide adequate oxygen to react with all the combustible components of the fuel. In practice, it is always necessary to provide somewhat more than the theoretical requirement, since the mixing process is never perfect and some of the oxygen brought in for combustion will not come into contact with molecules of combustible components. If too little air is supplied, some of the combustible material goes up the stack unburned. Large amounts of unburned combustible can result in a significant heat loss, although this condition rarely occurs. More commonly, the excess air significantly exceeds the required value and large amounts of heat are lost up the stack. Every attempt should be made to operate at the lowest excess air level possible, for efficiency. In essence, combustion control is aimed at effectively "walking the tightrope" between too much air and not enough.

Stack Gas Temperature: Because it represents a measure of the unrecoverable heat being wasted to the atmosphere, the temperature of the flue gases going up the stack is an important determinant of boiler efficiency. In considering installation of heat recovery equipment, you should remember that the flue gas temperature — less about 25°C — indicates a maximum to which a fluid can be heated. Its current value will, therefore, dictate possible applications for the recovered heat. Corrosion considerations do, however, set lower limits on the desirable value of the stack gas temperature. If fuel oil is used as fuel it is especially important to maintain a sufficient stack gas temperature to avoid condensation of water and sulphuric acid vapors on heater and chimney surfaces.

Steam or Process Fluid Conditions: The temperature, pressure, and rate of flow of the working fluid being heated reflect the all-important output of a boiler or process heater. They are, therefore, vital elements in determining the boiler's efficiency. In additon to indicating the state of boiler performance, variations in these quantities may, themselves, cause changes in the efficiency. For example, the rate of heat transfer from flue gas at a given temperature to steam flowing in a pipe will, in part, be determined by the velocity of the steam flow. Similarly, the temperature of the steam (and, by association, its pressure) will affect the heat transfer rate. Thus, for a given design, the boiler may have a different efficiency at one load level than at another. This affect is less pronounced when heat is transferred to a liquid (such as in a feedwater heater) than when it is transferred to a gas such as steam or air.

All of these parameters are interrelated through the complex processes of combustion and heat transfer which take place in a boiler or heater.

For example, improper fuel conditions require additional air for complete combustion. This excessive amount of air would, in turn, be reflected in an increase in stack gas temperature, as the increased velocity of the flue gases would generally cause them to pass over the heat transfer surfaces too fast to give up much of their heat content. Accompanying these changes would be a decrease in the rate of steam or process fluid available from the system.

A precise determination of boiler efficiency requires a detailed knowledge of fuel composition, atmospheric conditions, radiation losses from external furnace walls, and other data that are difficult to obtain in the average industrial installation. Flow-rates, temperatures, and pressures of fuel, steam, flue gas, combustion air, feedwater, and blowdown can be measured and an overall energy balance carried out to determine the boiler efficiency directly. However, an estimate, accurate within a few percent, can easily be made with a minimum of measured data by assuming some typical values for the fuel and air properties. This simple procedure uses the "Btu method" for combustion analysis, in which all quantities are referred to 10,000 Btu of heat content in the fuel input. Properties of a typical heavy fuel oil (about a No. 4 or No. 6) and a typical natural gas are used in the calculations.

The table on the next page outlines the step-by-step procedure. Step 1 lists the two required inputs — the percent of excess air and the flue gas exhaust temperature. These values are determined from measurements, as will be described later. In steps 2 through 7, the quantities of fuel, air, and moisture associated with 10,000 Btu of input heat are calculated. These quantities are used to determine the various heat losses attributable to the flue gas in Steps 8 through 10. Miscellaneous losses and the boiler efficiency are determined in Steps 11 and 12.

Boiler Efficiency Calculation Procedure

In general, the quickest and most accurate procedure to measure boiler efficiency is indirectly, *by the heat loss method.* Five measurements or inputs are required: the CO_2 or O_2 level (excess air), the stack temperature, the combustion air temperature, and the rated and actual boiler outputs. Two distinct losses occur. The first, dry flue gas loss (DFG) represents the sensible heat in the gases lost up the stack. The second, the hydrogen loss, is due to moisture in the flue gas formed from the combustion of hydrogen in the fuel. DFG depends on excess air and the difference in temperature between the flue gases and the combustion air. For a particular fuel, the hydrogen loss depends only on stack temperature and combustion air temperature.

In order to facilitate these calculations, graphical displays of the two heat losses are presented in the appendix to this booklet for three typical fuels: No. 6 and No. 2 fuel oils and natural gas. Another general chart appearing on the next page, enables the determination of the radiation loss for almost all boiler configurations. For a more detailed calculation of boiler performance, see the ASME Power Test Code for steam generating units.

Measurements — an Essential Ingredient.

As pointed out in the previous section, certain measurements are necessary to keep track of the performance of a boiler.

The most basic of these is the stack gas temperature. Though not adequate by itself to calculate the boiler efficiency, it does provide a running indicator of boiler performance; serious malfunctions will almost always show up instantly in the stack gas temperature. If the exhaust stack is accessible and visible from the operating area, the simplest way to measure stack temperature is with a dial-type thermometer. These are rugged and reliable devices which can be permanently installed directly in the stack. Some caution, however, must be exercised in using the indicated temperature for calculating the boiler efficiency, since there may be substantial variations in temperature across the stack and, in some installations, the thermometer may be subject to large errors due to radiation. A thermometer should be used which has an element long enough to extend well into the gas stream.

A continuous record of stack temperature may be obtained with a thermocouple (or other

Eight Steps to knowing your Boiler's Efficiency

1. Determine excess air from measured O_2 or CO_2.
2. Determine the difference between stack temperature and combustion air temperature (ΔT).
3. Determine sensible heat loss (any flue gas loss) using charts in the appendix to this booklet. (Intercept of ΔT line with excess air level.)
4. Determine loss due to hydrogen in fuel using charts in the appendix (intercept of the stack temperature and combustion air temperature lines).
5. Determine radiation loss from boiler casing using ABMA chart in the appendix, by following the boiler design load curve to where it meets operating load, then across to the vertical axis and down for water walls.
6. Add an estimate for unmeasured losses — 0.25 for natural gas, 0.50 for oil and 1.0 for coal.
7. Sum the losses 3→6.
8. Boiler efficiency = (100-losses)%.

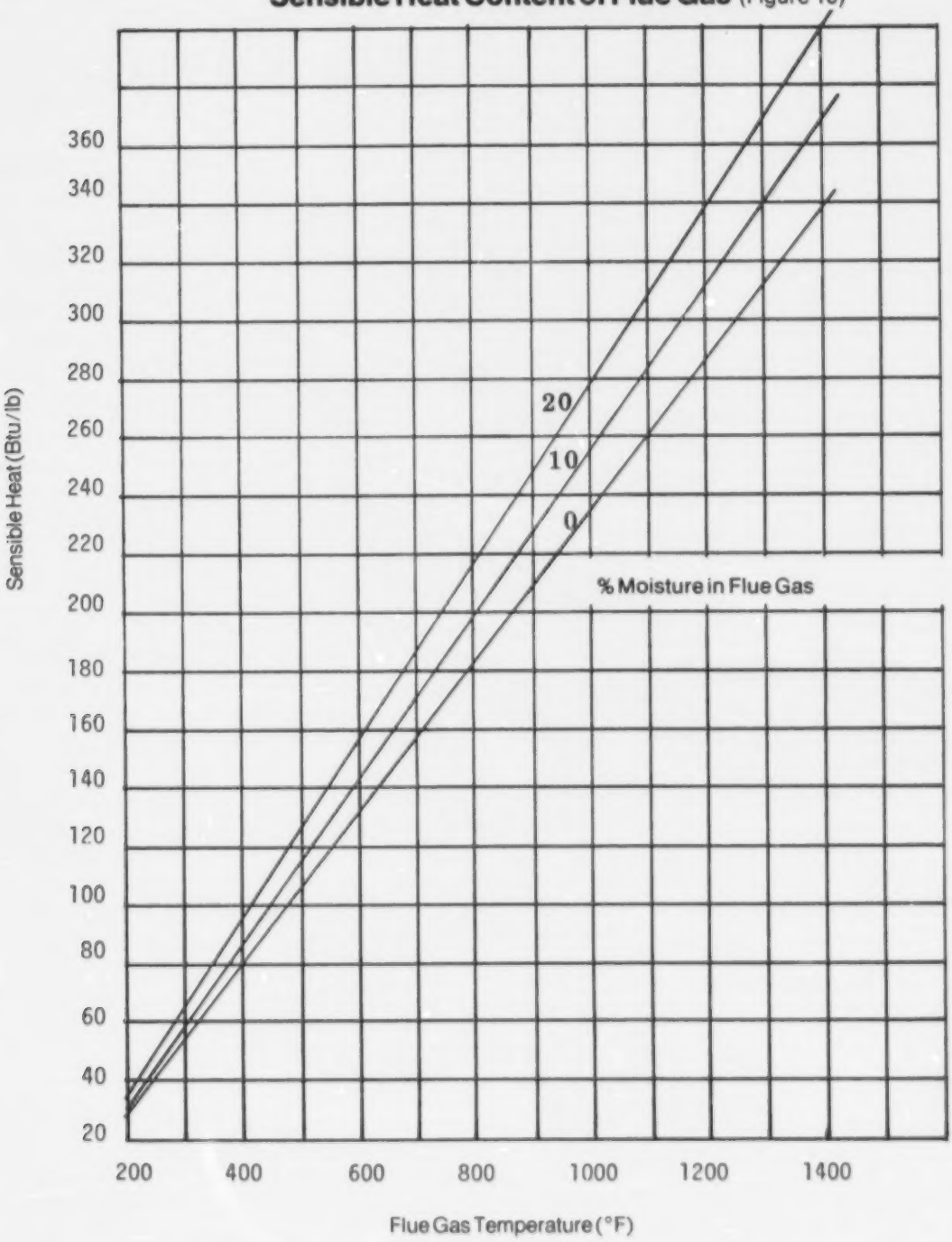
Example of Boiler Efficiency Calculations

The situation: A four waterwalled boiler rated at 30,000 lbs of steam per hour fires No. 2 or No. 6 oil or natural gas. At one third load (10,000 lbs.), the following measurements were taken for each fuel:

Fuel	Stack temp °F	Comb. air temp °F	O_2 (%)
No. 2 oil	600	100	7
No. 6 oil	600	100	7
Natural gas	550	100	7

Efficiency determination	No. 2	No. 6	Natural gas
1. Excess air (%)	45	45	45
2. Temperature diff. between stack and comb. air (°F)	500	500	450
3. Dry flue gas loss (sensible heat loss) (%)	13	13.2	11
4. Hydrogen loss (%)	6.7	6.9	11.6
5. Radiation loss (%)	2.6	2.6	2.6
6. Unmeasured losses (%)	.5	.5	.25
7. Total losses (%)	22.8	23.2	25.5
8. Efficiency (%)	77.2	76.8	74.5

Sensible Heat Content of Flue Gas (Figure 10)



sensing element) and an electronic recorder. Also available are recorders which utilize mechanical temperature sensing elements. The same precautions mentioned earlier regarding dial-type thermometers must be exercised in the installation of these devices.

An overall measure of boiler efficiency can be made by direct or indirect measurement of fuel and steam flow rates. Simple orifice-type flow meters can be installed directly in natural gas and steam lines, and the total flow over a period of time determined. If the steam conditions and

the fuel heating value are known, the boiler efficiency can easily be calculated. A similar measurement, although made indirectly, can be obtained with a ratio-type boiler meter. With this device, steam flow is measured by use of an orifice in the steam line, while the fuel flow is inferred from a measurement of the pressure drop of the flue gas as it passes through the boiler. To interpret these readings, you must calibrate the boiler with the device in place. Once the calibration is made, the ratio-type boiler meter may be used to continuously adjust the steam and air flows to some predetermined ratio which has been found, through tests, to give efficient combustion.

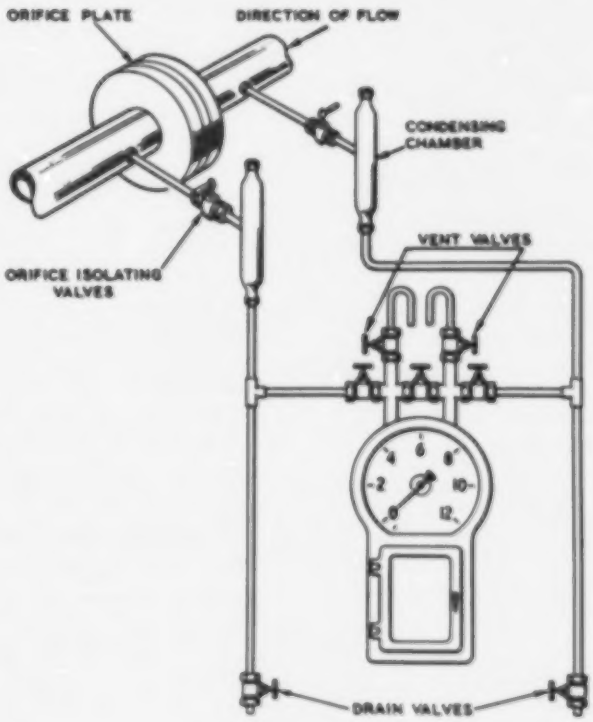
Perhaps the most accurate means of determining the state of combustion in a boiler or heater is the direct measurement of the chemical composition of the flue gas — in particular, the amount of oxygen and combustible components in the exhaust stack.

A low cost device, though the "messiest" method for determining gas composition, is an Orsat analyzer. Here, a sample of flue gas is drawn from the stack through a suitable sampling tube and bubbled successively through a series of pipettes, each of which contains a different chemical solution. Each of these solutions selectively absorbs one of the flue gas components, such as oxygen, carbon monoxide, or carbon dioxide. The reduction in volume of the sample as each gas is successively absorbed can be related to the quantity of the particular constituent that was present in the sample. With these quantities known, the percent of excess air used for combustion can be calculated.

Orsat analyzers are inexpensive, accurate enough for routine operational tests, and reasonably trouble-free. Maintenance personnel can easily be trained to use the apparatus. However, fresh reagents must be purchased or mixed every few weeks, and some calculation is necessary to convert the readings. Other devices are also available to give comparably accurate readings.

Portable combustion analyzers are easier and faster to use, and provide a direct reading of the percentage of oxygen or carbon dioxide in the flue gas sample. The sample is drawn continuously with a small pump housed in the analyzer case, through a filter which removes soot and other particulates and through a water trap.

Orifice Flow Meter with Mechanical Indicator
(Figure 11)



The most satisfactory oxygen analyzers are either paramagnetic or zirconium oxide types. However, an equally accurate measurement — providing the fuel composition is relatively constant or known — can be made with an infrared carbon dioxide analyzer. Portable combustion analyzers may cost more but the investment can be a worthwhile one.

For larger installations, it may be desirable to provide a continuous record or at least a continuous indication of oxygen and combustibles in the flue gas. Systems for continuous monitoring the stack gas components generally run several thousand dollars, but they can often pay for themselves in a short time when used to provide continuous combustion control of the system. If several boilers or heaters are in operation simultaneously, it is possible to utilize a multipoint system which draws gas samples sequentially from several remote points. By

sharing the expensive sensors and electronic equipment, the incremental cost per boiler is reduced considerably.

A regular flue gas monitoring program is a vital first element in improving the performance of boilers and process heaters. The devices described above, used with proper care, can provide the necessary information to properly adjust air dampers for correct combustion conditions. Of course, proper sealing and cleaning of sampling lines and filters must be maintained to insure the validity of readings. As will be discussed later, continuous stack gas monitoring systems are also important elements in some automatic boiler control systems.

Boiler performance can usually be improved through several means, often with substantial economic return. Improvements may be brought about by improved maintenance and boiler operation, improved controls, new burners, tightening boiler settings and installation of heat recovery equipment.

Maintenance and Operation.

The key to all improvements in boiler operation and maintenance is frequent determination of boiler performance by use of heat loss methods described previously. If several boilers are brought on line as needed, clearly the most obvious first step would be to sequence the use of each boiler in order of decreasing boiler efficiency; thus, at reduced load, only the most efficient boiler would be used, and less efficient units would be brought on line as required. Since boilers are generally designed for optimum performance near full load, better overall efficiency will be obtained with two boilers operating at full capacity than with three operating at part load.

Keeping heat transfer surfaces clean is another important consideration in maintaining peak performance in boilers. The accumulation of scale on the water side of boiler tubes, and the accumulation of soot and ash on the gas side, introduce resistance to the flow of heat from the gas to the water. This additional resistance is reflected in higher stack-gas temperatures and in additional fuel required to generate a given amount of steam.

Scale build-up on the water side is the result of precipitation of minerals, particularly iron salts and silica, at high temperatures. These build-ups can be very costly; for example, a one thirty-second inch layer of scale, high in iron and silica, can reduce boiler efficiency by five to seven percent. This can be worth literally thousands of dollars per year in increased fuel consumption. Boiler deposits can be controlled by proper water conditioning. The services of a water conditioning specialist should be employed to obtain an analysis of the chemical content of boiler feedwater and to make recommendations on systems to condition it for prevention of scaling. Or, if done on a routine basis, tubes may be cleaned mechanically. But the cost of this option in boiler down-time can be prohibitive.

Soot build-up on the gas side is a serious problem in oil-fired equipment, and should not be ignored even in "dual fuel" gas-fired boilers. Performance of boilers temporarily fired with oil can be seriously degraded in a short time, since the heat transfer surfaces are not optimally designed for operation with sooty fuels. Soot may be remove by manual cleaning, but if oil is fired on a regular basis, a better solution to the problem is the installation of soot blowers in the boiler. These devices periodically inject blasts of compressed air or steam against tube surfaces and blow off soot deposits.

As an example of the kind of gain realizable with soot blowers, one company installed soot blowers on their two fire-tube boilers, rated at 400 and 500 horsepower respectively. The use of the blowers resulted in a 7.5 percent net reduction in fuel consumption, using No. 6 fuel oil. At a fuel cost of 35¢ per gallon (U.S.), the company repaid its capital investment in about 14 months.

Improving Boiler Controls.

As pointed out in an earlier section, proper control of combustion processes involves striking a satisfactory compromise between inadequate and excess air. Most small package boilers are usually fitted with a simple mechanical control system, commonly called a "jackshaft" controller. In this system, the steam pressure is sensed as the basic control signal. This signal regulates a mechanical linkage attached to the fuel valve and combustion air dampers. The relative motion of the two elements can be adjusted somewhat through the use of special cams, but because of the mechanical linkage arrangement, it is not

possible on a routine basis to adjust the relative air and fuel flow rates manually. The "jackshaft" system is usually set for a particular operating condition when the boiler is first installed, and adjustments are made only infrequently thereafter. Because the system must accommodate variations in the heating value of the fuel and in the air conditions, it is always set to provide a high value of excess air, that is, to be conservative with air so as to prevent any fuels from entering the region of unburned combustibles. Typically, for a gas fired package boiler, this setting is around 30 to 40% excess air.

An improvement on this basic system is the so-called "parallel positioning" control system. In this system, steam pressure is again the driving signal, but the mechanical linkage is replaced by a parallel set of pneumatic or electronic drivers. These drivers actuate the fuel and air controls in a preset pattern. With parallel positioning, some operator control is usually provided. If some means of flue gas analysis is provided, improvement in performance over the simple jackshaft system can usually be obtained.

A third and yet more sophisticated form of control is known as "pressure balancing." In this system, the fuel pressure at the burner and the pressure drop of the flue gas through the furnace are sensed directly, and the system is controlled to proportion these pressures. The success of this system in maintaining accurate combustion control rests on the assumption that the flow rates of fuel and air are directly related to these pressures. While this is true in part, the flows also depend on certain other variables, such as fuel and air temperature. Furthermore, since the fuel heating value may vary somewhat, the mass flow rate indicated by the burner pressure is not a totally accurate indicator of the amount of air required for proper combustion. While this system is one step closer to a true fuel and air metering system, it must still control toward the conservative side. It is the most common system in larger plants.

The most sophisticated of the basic systems generally available utilizes direct measurement of the fuel and air flow rates by the installation of flow metering devices in the fuel and air systems. The fuel and air flow rate signals are sent to an electronic computing device, which then controls the fuel valve and air dampers in a pre-programmed manner. Refinements on this system include cross-limiting, which prevents fuel and air from exceeding preset limits relative to one another, and oxygen feedback, in which an oxygen sensor installed in the stack feeds an additional control signal to the computing device to be included in the control computation.

The chart shows the typical reduction in the amount of excess air which can be obtained using the various types of control systems described above. This table also shows installed costs for the various types of control systems, as estimated by one manufacturer in mid-1974. While these costs are in U.S. dollars and would be somewhat higher today, they are reasonably accurate relative to one another.

Graphs in the appendix to this book may be used to estimate the percentage savings that can be realized by a reduction in excess air to 10 percent for natural gas and 20 percent for No. 6 fuel oil.

For natural gas, suppose the existing system operates at 40% excess air and a stack temperature of 316°C. Combustion air temperature is 25°C. Entering the figure at the intersection of 40% air and 274°C stack differential, the heat loss is 12.4 percent. At 10 percent excess air, the heat loss has been reduced to 9.5 percent. The gain in efficiency is a full 2.9% for a fuel saving of nearly 4 percent.

Similarly for oil, with the same temperature conditions (but originally at 60% excess air), the original heat loss would be 15.2 percent — reduced to 11.4% at 20 percent excess air. This gives an efficiency gain of 3.8% and a fuel gain of 5%.

Based on this knowledge, installation of boiler controls can be seen to pay for itself within one to two years. In fact, reducing excess air also reduces stack temperature and further savings will result.

Boiler Heat Recovery Equipment.

Once proper combustion is maintained in the boiler or process heater, further improvements in performance must be obtained by recouping some of the losses inherent in the basic design of the equipment. Some older units are poorly insulated, particularly over endplates and access doors of packaged boilers. Improving this situation is quite simple and inexpensive, and may account for several percent improvement in fuel consumption.

Another measure which can be employed in older fire-tube boilers having high stack gas temperatures is the installation of turbulence promoters (sometimes called turbulators) to enhance the rate of heat transfer in the tubes. These are simply twisted strips of high melting point metal which are inserted in each tube to create swirl and turbulence in the hot gases flowing inside the tubes. These devices cost very little per tube; their installation can improve boiler efficiency by several percent.

In addition to these "quick fixes", substantial gains in performance can be obtained through the installation of heat recovery surfaces in the flue gas path — a subject dealt with in both the "Furnaces, kilns and ovens" section of this booklet and in the "Process design and heat recovery" booklet in this series. (See index in Book I.)

In years past, the low cost of fuel made it uneconomical to add sufficient heat transfer surfaces to the boiler to bring stack gas temperatures much below 260°C or 316°C. At today's prices, the capital investment required to add heat recovery surface can usually be repaid in a year or two through fuel savings. The heat recovered may be utilized in a number of ways, depending on the maximum temperature available from the flue gases.

If stack gas temperatures are several hundred degrees above the required steam temperature, it may be feasible to generate additional steam in

Fuel Savings Comparison of Boiler Combustion Control Systems

System Type	Btu Input Thous. Btu/Hr.	1974 Installed Cost $	Total Savings $/Yr	
			1.00/MBTU	2.00/MBTU
a) Jackshaft	10,000	18,000	0	0
	25,000	18,500	0	0
	50,000	19,000	0	0
b) Parallel (Operator Trim)	10,000	20,000	800	1,600
	25,000	20,500	2,000	4,000
	50,000	21,000	4,000	8,000
c) Pressure balancing	10,000	23,600	1,600	3,200
	25,000	24,100	4,500	9,000
	50,000	24,600	9,000	18,000
d) Metering (cross-limited)	10,000	28,600	3,500	7,000
	25,000	29,100	8,750	17,500
	50,000	29,600	17,500	35,000
e) Metering (cross-limited w/ O_2 correction)	10,000	34,100	4,100	8,200
	25,000	34,600	10,250	20,500
	50,000	35,100	20,500	41,000

1. % Fuel Saving Capability (600°F Flue Gas Temp.)

(a) Jackshaft	– 0% (Base)	(43% Excess Air)
(b) Parallel positioning	–1.0%	(37% Excess Air)
(c) Pressure balancing	–2.0%	(31% Excess Air)
(d) Metering w/ cross-limiting	–4.3%	(15% Excess Air)
(e) Metering w/ cross-limiting & O_2 feedback	–5.1%	(10% Excess Air)

2. Installed Cost vs. $ per year. Fuel Savings (8000 Hr./Yr. Operation) Fuel Costs $1.00/MMBTU and $2.00/MMBTU.

a waste heat boiler, using either natural or forced circulation. At somewhat lower stack temperatures, an "economizer" can be used to preheat the feedwater nearly to the boiling point before it enters the boiling section.

Other process fluids can also be heated in a waste heat recovery unit in addition to, or instead of, the boiler water itself. For example, it might prove economically advantageous to replace steam tracing lines on pipes or storage tanks with lines using an organic heat transfer fluid heated in a heat recovery unit. Other substances used in the process, such as raw materials, may also be preheated to reduce the fuel energy required to bring them to the necessary processing temperature. After the flue gas temperature has been reduced to within about 10°C of the incoming feedwater temperature, it may be used to preheat incoming combustion air.

Generally speaking, the lower limit practicality for flue gas temperatures is around 94°C for natural gas-fired equipment, and 149°C to 176°C for oil-fired boilers. The latter are limited by the necessity to avoid condensation of sulfuric acid vapors in the combustion products of sulfur bearing fuels.

Types of available heat recovery devices are discussed at length in the "Process Design" booklet; but as an example of the performance improvement obtainable with a flue gas heat recovery unit, consider the case of a small 500 horsepower package boiler operating with a 329°C stack temperature. The boiler feedwater enters at 100°C. Using an economizer to preheat the water to 149°C seems to be the best thing to do. But, a finned tube economizer to accomplish this purpose costs about $8,000 at the factory, or about $12,000 installed. The unit recovers about 1.5 million Btu per hour, which, at a gas cost of $2.00 per Mcf, saves about $3.00 per operating hour. The investment would pay for itself in a typical operation in under three years.

Pay-back periods for air preheaters are usually somewhat longer, due to the higher capital investment required for these units, but with fuel prices rising they still represent an attractive investment opportunity.

Significant amounts of heat can also be economically recovered from boiler blowdown by flashing to produce low pressure steam or by using a blowdown heat exchanger to heat incoming make-up water. In operations requiring large blowdown rates due to high dissolved solids, the heat recovery from such a system can amount to as much as several percent of the boiler input energy. (See also booklet on "Steam Management")

Most of the boilers and process heaters in use today were well designed for a low priced fuel economy. With the changing energy climate over the last several years, however, the technical and economic constraints have changed drastically. Reconsideration of boiler operations and of investments in equipment to improve their performance makes good business sense now, and will certainly make even better sense in the years to come.

Waste materials as fuel

While major strides have been made in the last decade in the incineration of municipal garbage to generate energy, the field of industrial incineration has remained largely undeveloped.

There were essentially two reasons why this happened:

1. With fuel at low cost, there was relatively little incentive to recover heat from incineration — and without heat recovery, economics favoured trucking wastes to a landfill site.
2. Some incinerators caused a pollution control problem of excessive particulate matter. Addition of auxiliary emission controls made incineration even less economically attractive.

Obviously, one of these factors has changed considerably. Fuel costs are not only much higher, they are still on the rise. As a result, both incineration and associated heat recovery technology are in full bloom. Starved air, fluidized bed and other types of incinerators can economically convert a wide range of solid, liquid and gaseous industrial wastes into recoverable heat energy, and frequently generate — with or without the help of pollution control equipment — a clean effluent stream of carbon dioxide and water vapour.

These incinerator units are available from a number of manufacturers in a range of sizes to accommodate many plants in the non-General Motors class and can be used both to generate

steam in a separate boiler or to heat air for various industrial applications through a heat exchanger. Case histories of industrial incinerator use are included in a later section of this booklet.

How does a "starved air" incinerator work?

Starved air incineration converts waste to recoverable heat in two steps. The first takes place in the incinerator's main combustion chamber where the following is accomplished:

- a limited percentage of the waste is thermally degraded for the generation of heat
- a portion of the waste is gasified for later use as a fuel in a secondary thermal reactor section
- the carbon-rich char residue is burned out on the hearth

In the main combustion chamber, approximately one-third of the total amount of air needed to achieve combustion is introduced through numerous small holes in the hearth. Rapid combustion occurs in the isolated areas near these orifices and the products of combustion are driven off at very high temperatures. Combustion products filter upward through the mass of waste in the main chamber — raising the temperature of the waste and causing it to gasify. The reactions that occur are complex — with both oxidizing and reducing conditions existing.

As the reaction proceeds, the refractory lining of the main chamber is heated, radiating heat into the trash and providing a thermal flywheel effect as trash is intermittently introduced into the main chamber. The high resulting temperature causes volatile products in the trash to be driven off in a gasification process. Since no oxygen is available for combustion, the gases are predominantly carbon monoxide and hydrocarbons. Finally, the carbon-rich residuals resulting from degasification are burned out on the hearth.

The second step occurs in the thermal reactor or "low-energy support afterburner" section. Here, combustion is completed by introducing preheated fresh air and igniting the gaseous mixture with a pilot light. Because the temperature of the gases from the main chamber is above 649°C as they enter the afterburner, the pilot light itself does not raise the overall temperature. However, as these gases ignite, temperatures reach 1204°C. Additional air is then introduced through a series of naturally inspirated sections until a minimum of 150% of required air is introduced, ensuring complete combustion.

Limiting the main chamber air input effectively minimizes the resultant turbulence and, hence, the particulate matter generated and entrained in the flue gas. Furthermore, the high pressures generally observed in conventional pyrolysis processes are eliminated, and the main chamber runs at negative pressure. The total combustion is especially pertinent to the heat recovery process since any associated heat exchange device is not subjected to high concentrations of particulate matter.

Heat reclamation.

With the adoption of the principle that thermal degradation of organic matter is controllable, it is now relatively easy, from an engineering viewpoint, to interface the incinerator with the appropriate heat exchange equipment. Recovery of heat from the flue gases is restricted only by the limitations of the heat transfer equipment. Many designs of commercially available flue gas heat recovery equipment have the potential of operating effectively with today's industrial incinerators.

One type of heat exchange equipment that offers a wide variety of design possiblities is the tubular heat exchanger. Multiple shell and tube passes can be provided, resulting in high transfer efficiencies. Hot media can flow inside or outside the tubes, the choice depending largely on maitenance requirements to retain operating efficiencies. A fairly wide selection of materials is available for the tubes, which normally will operate at a temperature approximately equal to the average of the flue gas and the ambient air — or about 399°C.

A typical installation of this type is a tube bundle heat exchanger mounted on the incinerator stack. In this case, the hot flue gases flow on the inside of the tube bundle, and plant air passes on the outside of the tubes. The temperature of the resulting hot air is controlled by adjusting the air flow rate through the exchanger. The heated air can be used for space conditioning or other purposes.

Steam generation.

For the use of flue gas to generate steam, a

preassembled, packaged boiler is recommended. Because the boiler units are nominally the same size and weight as the incinerator, stack mounting is not possible. The boiler is connected to the incinerator by a refractoried run of stack and can be fired by the incinerator alone or by the incinerator and an auxiliary burner. This type of heat recovery is extremely attractive when the plant utilizes either low or high-pressure steam for process heat in the manufacturing area or for building heat. The output of the boiler is connected to a conventional steam header and interconnected to the plant's main steam supply. When the incinerator is in operation, the heat recovery boiler serves as the primary system, and is supplemented by regular boilers when demand exceeds supply.

How economic is incineration vs. trucking?

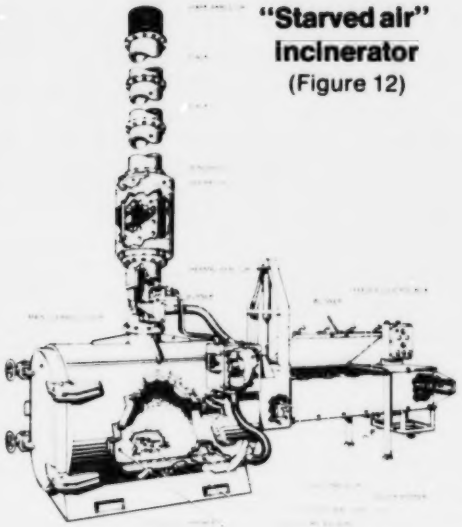
In an era of growing energy requirements and declining fuel supplies, onsite production of energy from wastes can offer significant economic advantages for industrial plants.

To determine if the waste materials generated in a plant can be economically processed for energy recovery, a solid waste and energy requirements survey must be carried out. Data to be obtained are:

1. types of solid waste generated
2. volume of waste material produced per day
3. density (in pounds per cubic yard) of each type of waste
4. total pounds of waste generated per day
5. Btu value per pound of waste
6. total daily Btu output of each type of waste

Dividing total pounds of waste per day by available burning hours (established by the plant engineer) determines the required burning rate in pounds per hour. The average Btu content per pound is calculated by dividing the total daily Btu content by the total pounds per day. The exact capacity of the required pyrolytic incinerator can then be determined.

Once the capital and installation costs of the equipment have been established, it is a simple matter to compare them with what the plant currently spends for hauling the wastes to a landfill or dump.



"Starved air" incinerator
(Figure 12)

The Btu data from the survey can then be used to compute fuel savings resulting from waste heat recovery.

A word of caution is, however, in order. In many cases, gathering and evaluating data for such a survey requires expert knowledge about waste-handling procedures and fuel cost evaluations. If this expertise is not readily available in the plant, it may be wise to seek outside help. Assistance is usually available from consultants, incinerator manufacturer or a representative in the area.

Typical applications.

The following installations are examples of how onsite incineration processes with auxiliary energy recovery equipment are currently being used in industry. (See also case histories.)

- A cement company burns spent crankcase oil to generate steam for use in cement kilns. The cement acts to neutralize acidics in the flue gas — with electrostatic precipitators on the stack removing remaining particulate matter.
- A Canadian lumber mill burns wood wastes to economically generate steam for use in lumber kilns. The owner claims that the rising price of other fuels would otherwise have forced him to close down his kilns.
- The lesson? If you have large quantities of combustible wastes of any kind at least explore the possibility of incineration as a means of saving energy and dollars.

CASE HISTORIES

Burning garbage heats drying oven

The situation: At a U.S. plant of John Deere Limited, management was conscious of a substantial yearly cost of nearly $40,000 to haul garbage from the plant to the nearest landfill site, but they were also conscious that this garbage had a high thermal content and if burned without causing undue air pollution could provide a valuable source of heat for a plant oven or process.

Action taken: The company installed a pyrolysis incinerator to burn nearly 20,000 lbs/day of garbage and, in conjunction with a heat recovery unit, to provide more than 3.9 MMBtu/hr to the plant's paint drying oven. Mix of the garbage burned is 50% lumber, 10% plastic, 40% miscellaneous, with corrugated waste baled and sold. Under the pyrolysis system, combustible gas is generated in the primary burning chamber so that the process "burns up its own smoke"—creating air emissions well within acceptable limits.

Energy savings: 3.9 MMBtu/hr = 14,600 Mcf/yr.

Dollar savings: 14,600 Mcf/yr @ $2.00 Mcf = $29,200./yr.

Additional savings in eliminated waste haulage: $38,400/yr.

Cost of improvement: For incinerator and heat recovery unit: $110,000.

Recommendation: Consider plant wastes as a potential heat source for your plant. As energy costs increase—along with trucking costs for haulage to disposal sites—waste incineration will represent an even more attractive energy conservation investment. It is estimated that, depending on composition, garbage is often worth up to $10/ton in recoverable energy.

Burning waste gas generates steam

The situation: An oil refinery has an acid gas by-product that contains a relatively high percentage of hydrogen sulfide and thus could not be vented to the atmosphere without treatment. Management seized the opportunity to make use of the 39,140 lb/hr of flue gas as source of waste heat.

Action taken: The H_2S rich gas is mixed with air and burned at 1371°C. No additional fuel supply is required. The combustion air is then cooled to 326°C in a waste recovery boiler where it generates 27,835 lb/hr of 175 psi steam. As a final step, the flue gas enters a converter which extracts sulfur.

Energy/dollar savings:

From the combustion gas,
Energy
= 39,140 lbs gas/hr x 0.366 Btu/lb°C x (1300—326°C)
= 26.5 MMBtu/hr

At a feedwater temperature of 148°C, the energy required to produce 1 lb of steam at 175 psig from water at 148°C is 933 Btu/lb (from steam table).
(With a 2% heat loss,

Steam flow
= 26.5 MMBtu/hr x 1/933 Btu/lb. x (1 — .02)
= 27,800 lb/hr
Based on a cost of $1.20 per 1,000 lb. of steam and 4,000 hour per year operation,
Annual savings
= 27,800 lb/hr x $1.20/1,000 lb x 4,000 hr/yr
= $133,000 per year.

Cost of improvement: Not available.

Recommendation: Evaluate waste products as energy sources to supply heat for the production of steam, for space heating and other plant requirements. Often these systems can be used to eliminate pollution problems.

Combustion air intake relocation saves energy

The situation: At the Nackawic, N.B. mill of St. Anne-Nackawic Pulp & Paper Company the recovery boiler—burning black liquor solids—forced draft fan air intake duct was located on the ground floor of the building where available air was a relatively cool (10-16°C in winter). Preheating of this combustion air to 93°C+ was carried out using steam coils.

Action taken: 50 feet of fibreglass ducting was added to relocate the air intake to the top floor of the building where temperatures are in the order of 38°C—reducing requirements for steam for combustion air preheating.

Energy savings: 4 MMBtu/hr.

Dollar savings: 4MMBtu/hr X 8,760 hrs/yr X $2.00/MMBtu/hr = $70,080/year.

Cost of improvement: $88,500.

Recommendation: Consider relocating air ducts at the source of warmest available air to reduce preheating requirements. In this particular application, costs were particularly high due to need to reinforce ducting and attach firmly to the building to reduce vibrations—and due to design complications tying into the existing air intake.

Combustion air preheated with kaolin

The situation: A company which manufactures kaolin powder as a base material for paint realized that it could recover considerable amounts of heat previously vented to the atmosphere from its process. A hot clay air mixture with a temperature of 788°C and a flow rate of 41,000 lb/hr to the bagging room offered a convenient source of energy to preheat combustion air for a gas-fired furnace.

Action taken: A heat exchanger was installed in which the kaolin air mixture is cooled from 788°C to 204°C and the heat acquired used to preheat at 7950 cfm or furnace combustion air to 616°C from its ambient temperature of approximately 26°C.

Energy savings: 41,000 lb/hr × 0.308 Btu/lb°C × (788-204)°C = 13.3 MMBtu/hr

With the heat exchanger operating 6000 hr/yr at its design efficiency rate of 70 per cent, yearly energy savings = .70 × 13.3 MMBtu/hr × 6000 hr/yr = 55,800 MMBtu/yr

Dollar savings: 55,800 MMBtu/yr = 55,800 Mcf @ $2.00 Mcf = $111,600/year

Cost of installation: $90,000.

Recommendation: Don't overlook any possible source of waste heat for preheating combustion air or for other applications.

Garbage supplies heat for plant

The situation: A fabricator of plywood, fibreboard and insulating materials in Wisconsin opened a new plant and found it impossible to get guaranteed supplies of natural gas. In retrospect it may now appear fortunate that natural gas is in short supply because it forced the company to look at 5,000 tons of combustible waste (which would have been hauled away to a city incinerator) as fuel for heating the plant. It was seen that the plant would only be able to use 60 percent of the heat generated by burning trash, with the remaining 40 percent being discharged to the atmosphere.

Action taken: The company installed a pyrolysis type incinerator (with oil as a standby fuel for weekends) which, in concert with a heat recovery system is recovering a net 5,500,000 Btu/hr. In the system, waste scraps of raw material, office and other trash, are pushed into a primary chamber from a feeder bin by hydraulic ram. Here they are burned under oxygen lean conditions, which produces a combustible gas. When this gas rises with the smoke into the base of the emission stack it passes through a thermal reactor where air is brought in from the outside. Gas and smoke are then burned at temperatures of around 1093°C. 982°C hot air is diverted by a fan into a boiler where it heats water which, in turn, heats the hot air used for plant conditioning.

Energy savings: 5.5MM Btu/hr = 34,320 MMBtu/yr = 34,320 Mcf/yr

Dollar savings: 34,320 Mcf/yr @ $2.00 /Mcf = $68,640./yr.
Approximately $20,000/yr in haulage costs for waste was also saved.

Cost of improvement: Approximately $150,000.

Recommendation: Attempt to reduce the amount of "garbage" generated by your plant, but where waste production is unavoidable and is available in sufficient quantities, look to it as a source of heat for various purposes. Pyrolysis incinerators generally produce a low volume of dry, sterile ash. In the case of the Wisconsin company, management is now studying ways to direct some of the unused heat to paint drying ovens—further reducing the firm's energy bills.

Heat wheel captures waste heat from annealing furnace

The situation: Annealing furnaces used for heat treating metal products in Standard Tube of Canada's Woodstock, Ontario plant were consuming major amounts of plant oxygen and creating excessive amounts of carbon dioxide. The result was a request from the Ontario government to consider a ventilation system. Standard Tube's approach was to provide the needed ventilation and at the same time capture the latent energy in exhaust and other heated air that was accumulating just below the plant roof.

Action taken: The decision was taken to install a metal heat wheel to capture waste heat and pre-heat plant make-up air during the winter. An H-shaped grid collects 30,000 cfm of 49°C air at ceiling (2,500 cfm oven exhaust air plus 27,500 cfm ambient air heated by oven's radiant heat) and feeds it into the heat wheel.
Outside air is heated to approximately 32°C, depending on outside ambient temperatures, before being ducted to plant floor level.
A manually operated bypass allows direct venting and air intake whenever outside air temperature exceeds a predetermined point.

Energy savings: Based on a 210-day use cycle, savings (over the conventional exhausting of warm air and heating make-up air with direct fired gas heaters) are estimated at 10,000 MM Btu's per year on a three shift basis over a 210-day use cycle.

Dollar savings: Savings approach $20,000 per year, based on a $2.00/Mcf cost of gas.

Cost of improvement: Cost of the heat wheel itself was $8,000. Capital required for entire project including labour, duct work, etc. totalled $60,000. Experience so far indicated that the investment will be recouped within a 3-year payback period.

Recommendation: Consider the use of heat exchange devices included heat wheels to recover heat from exhaust gases. In the case of Standard Tube, a ventilation system was required in any event and the actual payback period related solely to the use of the heat wheel is in the order of one year. Similar economics may well apply to an application in your plant.

Improved furnace insulation cuts heat loss

The situation: Bending furnaces with a maximum internal temperature of 649°C in a U.S. plant had sidewall and suspended crowns constructed of heavy red and refractory brick. Although the walls were thick, it was obvious to management that heavy heat losses in the furnace was being incurred.

Action taken: The crown of the furnaces was replaced with sheet metal and low density ceramic fibre insulation. Insulation was also added to furnace walls.

Energy savings: Due to heat up time reduction from 2½ hrs/day to 30 min/day = 3 Mcfd. Total daily savings = 4.4 Mcfd.

Dollar savings: 4.4 Mcfd @ $2.00 Mcf = $8.80/day × 210 days/yr = $1,848/year.

Cost of improvement: $1,750.

Recommendation: Consider similar insulation projects for ovens, kilns, or furnaces in your plant. In this case, there were a number of other intangible benefits which were not taken into account in justifying the investment involved: ambient temperatures near the furnaces were lowered by 10°C, production rates and product quality were improved and maintenance requirements were reduced.

Incinerator effluent preheats oven air

The situation: At the Wallaceburg, Ontario container factory of Libby, McNeill & Libby, provincial air emission standards dictated the installation of a fume incinerator to control hydrocarbon emissions, eliminate air and odour

pollution and remove the problem of condensate particles contaminating tin plate moving through the gas-fired sheet oven.

Action taken: The company installed an incinerator incorporating a heat recovery system to utilize incinerator exhaust to preheat oven entering air.

Energy savings: A maximum of 1.1 MMBtu/hr is supplied by the incinerator effluent to preheat oven air.

Dollar savings; 1.1 MMBtu/hr × 4500 hr/yr = 4950 MMbtu/yr = 4950 Mcf/yr @ $2.00/Mcf = $9,900/year.

Cost of improvement: Of a total project cost of nearly $300,000, costs attributable to the recovery system amounted to just over $150,000.

Recommendation: Look closely at pollution abatement program as ideal opportunities to "piggyback" energy conservation programs. In the case of Libby's, use of the heat recovery system resulted in natural gas consumption for the oven and incinerator totalling less than 10 percent higher than natural gas usage required previously for the oven alone.

Insulation of continuous cooker cuts heat loss

The situation: At the Wallaceburg plant of Libby, McNeill, and Libby, management is aware that heat loss from Sterilmatics (automatic continuous steam cookers for sterilizing tin food products) represents one of the significant energy savings opportunities within the plant.

Action taken: As a result they are planning to insulate the three Sterilmatics at the plant using a 3-inch polyurethane shell enclosed in a 26-gauge stainless steel jacket.

Energy/Dollar savings: Approximately 6,350 Mcf @ $2.00/Mcf = $12,700/year.

Cost of improvement: $21,000.

Recommendation: Look to insulation of any combustion or heat process equipment to reduce fuel consumption.

Modification of firing processes minimizes energy use

The situation: A U.S. company involved in the manufacture of computer components was faced with a situation in which computer memory cores were being fired in a kiln for 18-24 hours when all that was required was a few seconds at the maximum temperature (usually 1,000°C). The long cycle was necessitated by the characteristics of the furnace and of the plates which supported the cores. First, it was difficult to be sure that the cores reached the right temperature without overshoot; second, the plates were sensitive to temperature shock and had to be heated and cooled slowly.

Action taken: In an improved process, the cores were spread on a woven belt of platinum wire which carried them continuously through a small tube furnace about four feet long. The cores were exposed to high temperature for only about 15-20 seconds. The continuous process permitted frequent sample testing of the cores with feed-back of information for any desired adjustment of temperature, oxygen content of the furnace atmosphere, etc. As a result the yield of "good" cores at the final quality control test station was more than doubled.

Energy savings: Process changes reduced the energy requirement for firing computer cores from 120 Kwh/M cores to slightly less than 0.9 Kwh/M cores.

Dollar savings/Cost of improvement: Not available.

Recommendation: Keep kiln firing schedules as short as possible and reduce to a minimum the amount of heat loss through heating and cooling the supporting kiln furniture. Wherever possible, continuous firing should be implemented.

New boiler pays for itself promptly

The situation: A U.S. food processing company reviewed its capabilities to increase production and concluded it would be to its advantage to "reboiler" their plant. Two original boilers with oil burners had earlier been converted to gas/oil firing and were rated at 600 HP each. In order to provide additional peak capacity, a 200 HP boiler

was rented each year for August and September. Since business was expanding, even more steam would be needed in the future. It was also recognized that gas supplies were being curtailed and changeover of this old gas burner to oil firing was a bothersome process that took many man hours—and, tests indicated that the old boilers were operating at a fuel-to-steam efficiency of about 70%.

Action taken: It was decided that a new 800 HP boiler (85% efficiency) with a combination gas and oil burner be installed. At the same time, a shell and tube heat exchanger was installed to preheat boiler feed water with 66°C waste water from the blanchers, cookers and brine heater.

Energy/dollar savings: The total cost of the heat exchanger installed was $3,000, and the fuel saved due to the heat recovered was approximately $6,000/yr. The higher efficiency of the new boiler, compared to the old boilers, resulted in further cost savings:

Old boilers: 1,799,981 Cases with 66,177 MMBtu
New boilers: 1,821,285 Cases with 48,812 MMBtu

Gain: 21,304 Cases with 17,365 MMBtu

This saved an additional $28,000 in fuel costs. Two other factors contributed an additional $20,000 savings. First, a rental boiler was not required for peak periods. Second, more than 2,000 man hours were saved, since the new boiler was automatic, and changeover from gas to oil only takes minutes, not hours.

Total savings: $48,000/yr + $6,000/yr = $54,000/year

Cost of Improvement: $67,000.

Recommendation: Replace outdated, inefficient combustion equipment wherever energy and other savings make it economic to do so. Some manufacturers guarantee high fuel to steam efficiency in new boilers.

Noxious material burned to generate steam

The situation: A chemical manufacturing firm was faced with a disposal problem for substantial quantities of a liquid chemical by-product.

Action taken: The company installed a boiler to burn the by-product which has an average heating value of 6,000 Btu/lb and is completely oxidized at 982°C. The boiler has special designs to control boiler and soot deposits and generates 64,000 lb/yr of 300 psig process steam. A total of 200,000 cfm of flue gas is produced and quenched to 94°C before passing through a scrubber into the stack.

Energy/dollar savings: The flue gas flow rate corresponding to 200,000 cfm at 982°C is 170,000 lb/hr. The specific heat of the flue gas is 0.30 Btu/lb °F and the saturation temperature of 300 psig steam is 218°C. The waste heat boiler was designed to have an exit flue gas temperature of 260°C. Therefore, the energy available from the flue gas is:
Energy available — 170,000 lb/hr × 0.30 Btu/lb. °C × (982 − 260) = 66.3 MMBtu/hr.
If the feedwater is at 104°C, the heat required to produce saturated 300 psig steam is 1027 Btu/lb. Allowing for 1% heat loss;
Steam production = 66.3 MMBtu/hr × 1 lb/1027 Btu X 0.99 = 63,900 lb/hr.

The company was paying $1.25 per 1,000 lbs. of steam when it was produced from fuel oil. Based on 3,000 hrs. per year operation;
Dollar savings = 63,900 lb. steam/hr × $1.25/1,000 lb. steam × 3,000 hr/year = $240,000 per year.

No allowance was made for savings due to reduced disposal costs.

Cost of improvement: Boiler = $400,000.
Installation and accessories = $300,000.

Recommendation: Liquid by-products and solvents should be considered as fuel sources for steam generation, space heating, etc. Higher prices for fuels make these processes more economical.

Oxygen analysers installed, combustion controls upgraded on boilers

The situation: Labatt Breweries of Canada Limited's boilers function using a batch process. It is physically impossible to respond manually to the changing load.

Action taken: Labatts decided to install oxygen analyzers and upgrade to fully automatic the

combustion controls on boilers in its Montreal Brewery. The automatic controls make it possible to respond quickly to the load change factor.

Energy/dollar savings: Projected savings are 1.25% of fuel consumption or 5,000 Mcf of natural gas per year.

Cost of improvement: $60,000 installed. The project was justified economically by assuming a 15% escalation in fuel cost each year for the first three years and a 10% per year escalation thereafter. This would mean a discounted cash flow rate of return on investment of 20% with a payback period of 4 years.

Recommendation: Use projections for future cost escalations to determine economic viability for energy conservation projects.

Preheated combustion air saves gas at glass plant

The situation: A glass company, a part of ordinary maintenance, decided to save energy by using stack recuperator to preheat combustion air. A day tank was rebuilt and provided with two flat-flame burners, a 16-oz. blower, and a zero regulator air-gas mixer. The tank was oval, approximately 6 ft. × 8 ft. with a 12-inch high metal lining. The holding capacity was 3.5 tons of glass.

Action taken: While the equipment and tank design were unchanged, the stack operation was changed from downdraft to updraft. The recuperator was set on a refractory stack base approximately 48 inches high and the new stack was built over the top of the existing stack at floor level with a cleanout and/or cold air entrance. The unit was designed to withstand 1149°C – 1260°C, using ⅛ inch Incoloy 800 for the recuperator and 1/16 inch stainless steel for the stack. The centre pipe was approximately 7 ft. long and 24 in. in diameter, with vertical strips 3 in. long and ⅜ in. wide welded on the outside. A larger concentric pipe of the same length fitted over the centre pipe, leaving an air space of ⅜ in. between the pipes. The outer pipe was covered with insulation and the insulation was then covered with a metal shield. Six-inch diameter inlet and outlet pipes were fitted to the outer pipe.

Energy savings: The annual (50 weeks) gas savings for melting and holding amounted to 4,212,500 cu. ft./yr (16,587,500 cu. ft./yr. before installation of the recuperator and 12,375,000 cu. ft./yr. after installation) for melting and holding operations.

Dollar savings: At a cost of $2.00 Mcf, the savings for fuel are: (4212.5)($2.00) = $8,425/year.

Cost of improvement: The 1971 cost of installation was $4,520—doubling this to $9,040 for 1977 gives a payback of $\frac{\$9,040}{\$8,425} = 1.07$ years.

Recommendation: Stack recuperators can be an attractive option to preheat combustion or other air.

Recuperators heat make-up air with kiln exhaust

The situation: At a Canadian abrasives products finishing plant, an energy audit showed that substantial amounts of heat were being wasted in the form of kiln flue gas.

Action taken: Over a period of four months, vertical, surface-type recuperator heat exchangers were installed on each of the plant's six kiln flues. Over a 10-day cycle necessary to avoid heat shock to the grinding wheel being baked, flue gas varies in temperature between 94°C and 982°C. Fresh air is preheated by 5°C to 30°C depending on the heat of flue gas and finally "trimmed" by a direct gas fired heater with a 25:1 turndown ratio. The air then passes into the plant ventilation system.

Energy savings: 4,680 MMBtu/yr = 4,680 Mcf/yr.

Dollar savings: 4,680 Mcf/yr @ $2.00/Mcf. = $9,360/year.

Cost of improvement: $17,000.

Recommendation: Look to flue gases as an available source of waste heat. Pay full attention to operator education with the new system. Experience shows that with proper education, start-up problems can be minimized.

Reducing excess air in steel foundry furnace

The situation: Dominion Foundries and Steel's fuel-fired heat treating furnaces often require excess air to ensure temperature uniformity. However, the amount of excess air on a particular furnace is sometimes higher than that required for temperature uniformity.

Action taken: In one of the furnaces in the steel foundry, air flow must be held constant throughout the cycle. Dominion Foundries and Steel tried reducing this constant flow of air on successive cycles in small increments while carefully monitoring furnace temperature spread and product quality. The company found that it was able to reduce air flow by about 40% for this particular 10 × 21½ ft. furnace, without significantly affecting temperature uniformity.

Energy savings: This measure saved 12 MMBtu/cycle × 416 cycles/year = 4,992 MMBtu/year.

Dollar savings: 4,992 MMBtu/year coke oven gas at $2.00/MMBtu = $9,984/year.
Figures for cost of testing the air flow for the furnace are not available.

Recommendation: Each furnace has to be tested as an entity of its own, and care must be taken so that the air is not cut back too much causing damage due to lack of temperature uniformity. If you can spare the money and time to conduct the tests properly, this measure can be a big energy saver.

Scrap plastic burned in boiler

The situation: At a General Motors plant, 24,000 lbs. per year of scrap plastic was granulated and sent to a landfill site for disposal. One major boiler was fueled with stoker coal, despite the high Btu content of the plastic waste.

Action taken: A simple vacuum system was installed on the boiler to allow mixing of coal with the granulated acrylic, ABS, polypropylene and polycarbonate material.

Dollar savings: 360 MMBtu/yr = 13.8 tons stoker coal @ $40/ton = $552/year.

Cost of improvement: $750.00.

Recommendation: Careful consideration should be given to the use of plastic and other waste materials as combustion fuels (see other case histories). To the basic energy savings offered in many cases must be added the elimination of substantial waste removal expenses. Plastic materials have a high thermal content and generally leave relatively little ash, however, some such as polyvinyl chloride give off noxious gases and other residues when burned and must be approached with a good deal of understanding before any attempt is made to utilize them as a source of energy.

Slot furnace modernization improves efficiency

The situation: John Deere Limited's Welland works utilizes a number of slot furnaces. As part of an overall energy audit, the company realized that these furnaces could be re-designed to make more efficient use of energy. In fact, preliminary estimates indicate that a new design furnace could save approximately 19 percent on fuel consumption. Actual in use savings proved to be more than twice this amount.

Action taken: After prototype testing, new furnaces were put in place which incorporated the following features.

—Castable ceramic lining — rather than refractory brick.
—Preheating of combustion air to 400° by mixing ambient air with furnace exhaust.
—Replacement of water-cooled heat shields with fibrefrax ceramic fibre.
—A new design arch block with improved heat reflection which can reduce material heat-up time by up to 40 percent.
—Use of individual 3 hp blowers rather than a central 40 hp blower system.

No external approvals were required and old furnaces were replaced, without interrupting production, at the rate of about 1 furnace per month.

Energy savings: 45 percent overall = 580 MMBtu/year.

Dollar savings: 580 MMBtu/yr = 3,135 gal @ $.35 = $1,097/year.

Cost of Improvement: $5,300 per furnace — representing a 41% discounted cash flow return on investment over a 3-year cash payback.

Recommendation: Explore the modification or re-designing of existing equipment in your plant or foundry. Do not be deterred by, for example, a three year "payback". As in the case of John Deere, a dcf rate of return analysis along with other factors (annual maintenance costs were reduced by $870 per furnace) was enough to convince management of the investing of money to save energy — and make money.

Waste oil provides heat for boiler

The situation: At the International Harvester plant in Chatham, Ontario, 5,000 gals/yr. used lubrication oil (such as spent crankcase oil) was being discarded as an unusable waste material. The company realized that, if gathered and stored, waste oil could be used as a fuel for combustion.

Action taken: The company instituted a programme in which waste oil is collected from various locations around the plant such as lift truck and vehicle maintenance departments and deposited in a central holding tank. Three times during the year the oil is transported to the main boiler house fuel tank and mixed with No. 6 Bunker C fuel oil.
The main fuel tank has a capacity of 50,000 gallons and is held at approximately 66°C. The relatively high temperature of the fuel oil, coupled with the fact that the lube oil is introduced into the bottom of the tank in approximately 1,750 gallon lots, enables a good mix to be maintained. No noticeable stratification is apparent.

Energy/dollar savings: 5,000 gals/yr. salvaged oil provides an estimated 960 MMBtu/yr @ $2.00/MMBtu. = $1,920/yr.

Cost of Improvement: Labour costs for transporting and pumping oil = $80/year.

Recommendation: Look to a variety of waste materials as potential boiler, kiln or furnace fuels.

Tips on saving money through combustion control

Furnaces, Kilns and Ovens.

1. Calculate and plot boiler efficiency daily.
2. Establish a definite burner maintenance schedule.
3. Regularly adjust burners for most efficient operation.
4. Heat oil to proper temperature for good atomization.
5. Eliminate combustible gas in flue gas.
6. Reduce combustion air flow to optimum level.
7. Replace obsolete burners with more efficient ones.
8. Use waste and by-products as fuel wherever possible.
9. Limit and control secondary combustion air in furnace operations.
10. Calculate a "heat balance" for all combustion equipment to better understand where energy is dissipated or used.
11. Utilize hot stack gases as an energy source.
12. Insulate furnaces, kilns and ovens to minimize heat loss.
13. Control infiltration of cold air into furnaces.
14. Shut down idle combustion whenever possible.
15. Consider cam controllers or other systems to control the shut down cycle on combustion equipment.
16. Schedule plant operations for "full load" operations on combustion equipment.
17. Minimize energy loss during loading and unloading (cycling).
18. Eliminate "overdesign" in equipment and practices.
19. Regularly analyze flue gases.
20. Watch for gasket and seal leaks caused by frequent opening and closing of the furnace.
21. Look into automatically controlled flue dampers.

Industrial boilers.

1. Look to stack gas temperatures as a running indicator of boiler performance.
2. Carry out frequent checks of boiler performance.
3. If more than one boiler is in use, sequence boiler use in decreasing order of efficiency.
4. Keep as many boilers as possible operating near full load (rather than having a greater number operating at partial capacity).
5. Keep all heat transfer surfaces clean.
6. Improve boiler control systems.
7. Reduce "excess air" to increase boiler efficiency.
8. Look to waste heat boilers and/or economizers to utilize hot stack gases.
9. Utilize boiler blowdown as flash steam or in a blowdown heat exchanger to preheat make-up water.
10. Reduce blowdown through feedwater control.

See "Saving Money Through Steam and Compressed Air Management" for further tips.

SI USAGE

Derived SI Units Having Special Names

Quantity	Unit	Formula	Symbol
Frequency	hertz	s^{-1}	Hz
Force	newton	$kg \cdot m/s^2$	N
Pressure or Stress	pascal	N/m^2	Pa
Energy or Work	joule	N·m	J
Power	watt	J/s	W
Electric charge	coulomb	A·s	C
Electric potential	volt	W/A	V
Electric resistance	ohm	V/A	Ω
Electric conductance	siemens	A/V	S
Electric capacitance	farad	C/V	F
Magnetic flux	weber	V·s	Wb
Magnetic flux density	tesla	Wb/m^2	T
Inductance	henry	Wb/A	H
Luminous flux	lumen	cd·sr	lm
Illuminance	lux	lm/m^2	lx

Common Equivalents and Conversions

Approximate Common Equivalents
1 in. = 25 mm
1 ft. = 0.30 m
1 yard = 0.91 m
1 mile = 1.6 km
1 sq. in. = 6.5 cm^2
1 sq. ft. = 0.09 m^2
1 sq. yd. = 0.84 m^2
1 acre = 0.40 ha
1 cu. in. = 16 cm^3
1 cu. ft. = 28 dm^3
1 cu. yd. = 0.76 m^3
1 quart (liq) = 1.1 ℓ
1 gallon = 4.5 ℓ
1 oz. (Avdp.) = 28 g
1 lb. (Avdp.) = 0.45 kg
1 hp (UK) = 0.746 kW
1 lbf. = 4.4 N
1 psi = 6.9 kPa

Some Other Derived SI Units

Quantity	Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Velocity-angular	radian per second	rad/s
Velocity-linear	metre per second	m/s
Acceleration-angular	radian per second squared	rad/s^2
Acceleration-linear	metre per second squared	m/s^2
Density (mass per unit volume)	kilogram per cubic metre	kg/m^3
Moment of force	newton metre	N·m
Viscosity-dynamic	pascal second	Pa·s
Thermal conductivity	watt per metre kelvin	W/(m·K)
Thermal flux density, Irradiance	watt per square metre	W/m^2
Thermal capacity or Entropy	joule per kelvin	J/K
Permeability	henry per metre	H/m
Permittivity	farad per metre	F/m
Thermal resistance (R value)	square metre kelvin per watt	m^2K/w
Energy density	joule per cubic metre	J/m^3

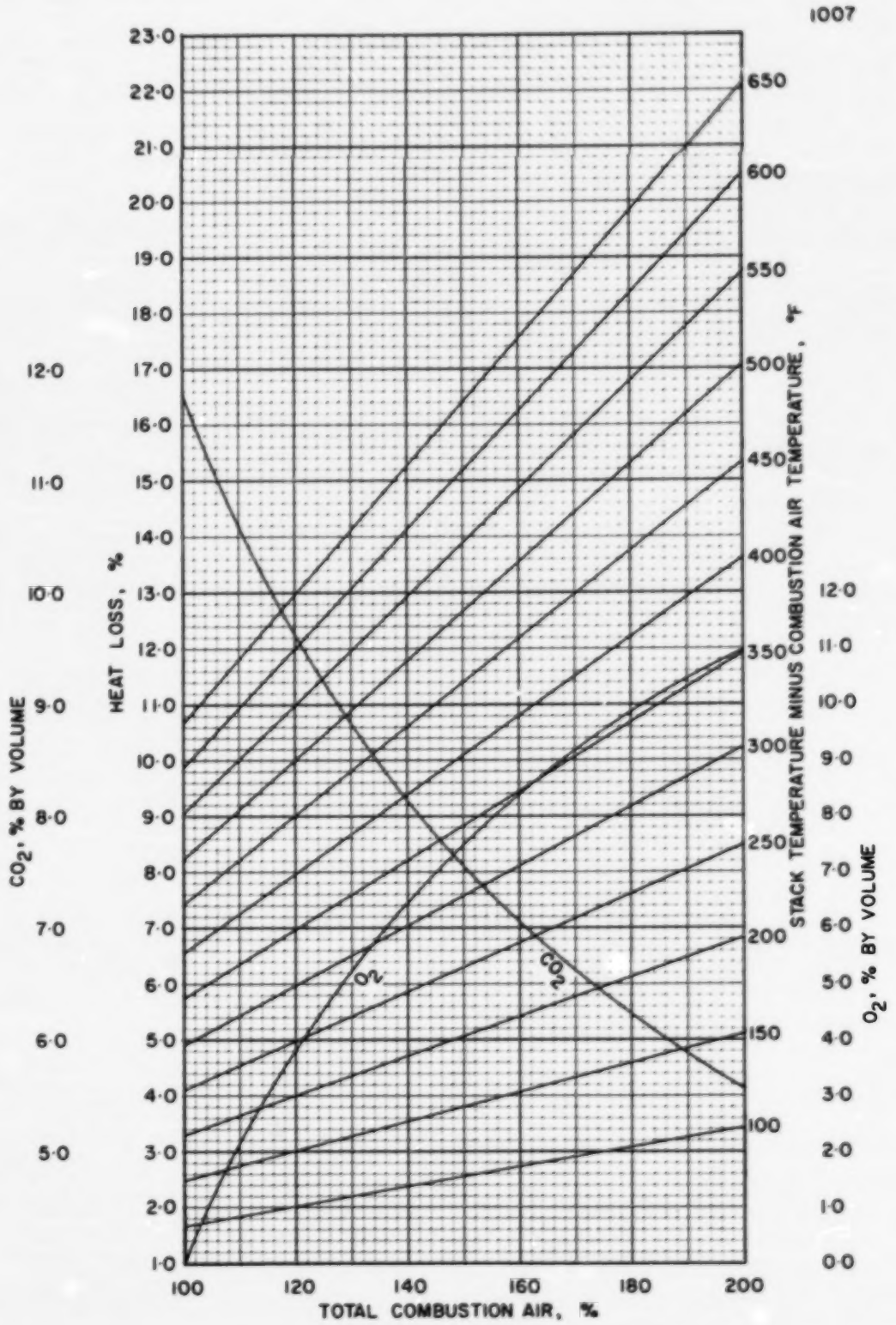
SI PREFIXES

Multiplying Factor	Prefix	Symbol
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deca	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

Some Non-SI Units Used with the SI

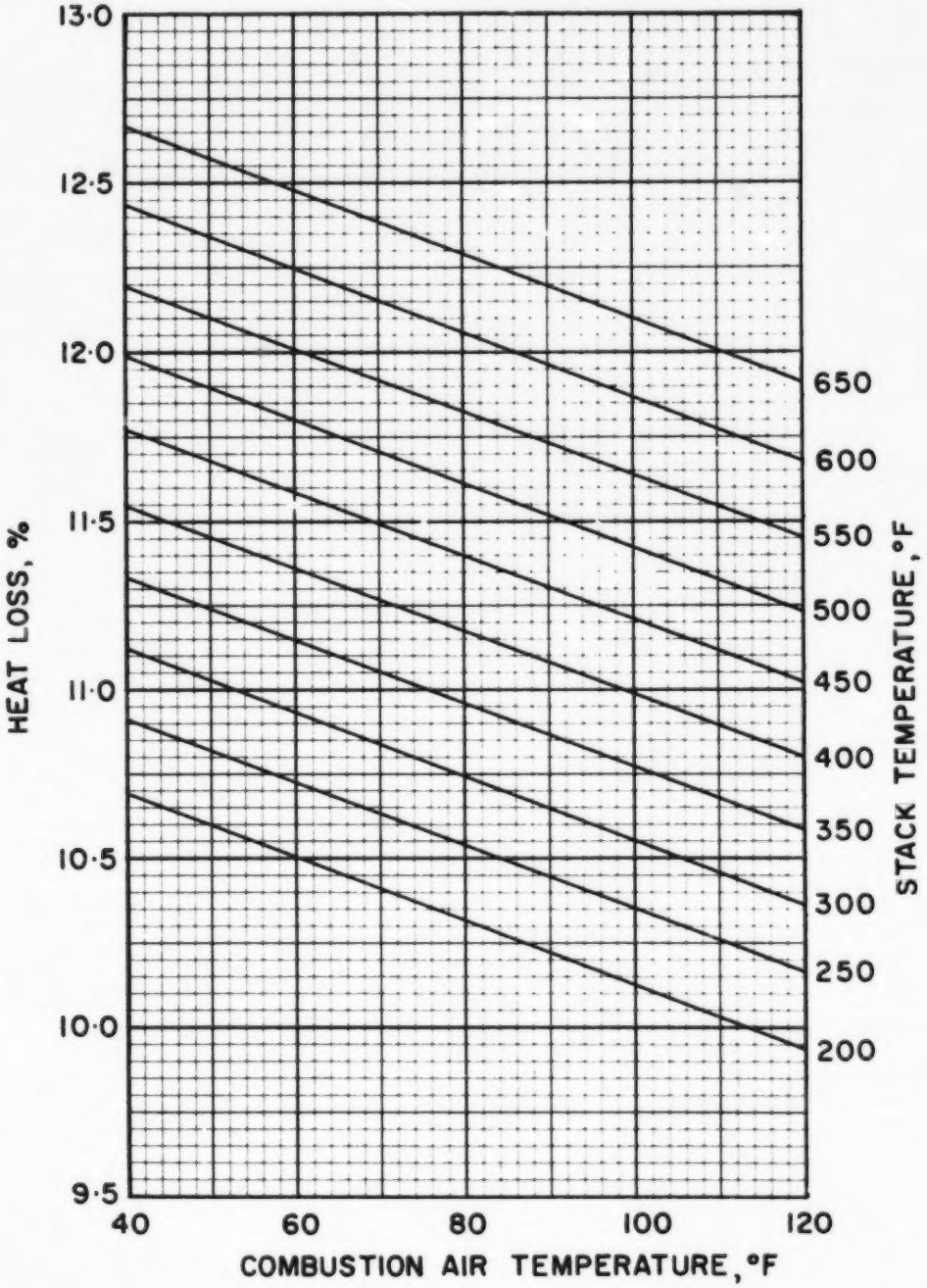
Unit	Symbol	Value in SI Units
minute	min	1 min = 60 s
hour	h	1 h = 3600 s
day	d	1 d = 86 400 s
degree (of arc)	°	$1^\circ = (\pi/180)$ rad
minute (of arc)	′	$1' = (\pi/10\,800)$ rad
second (of arc)	″	$1'' = (\pi/648\,000)$ rad
litre	l or ℓ	1 ℓ = 1 dm^3 = 10^{-3} m^3
tonne	t	1 t = 10^3 kg = 1000 kg
hectare	ha	1 ha = 10 000 m^2

Appendix



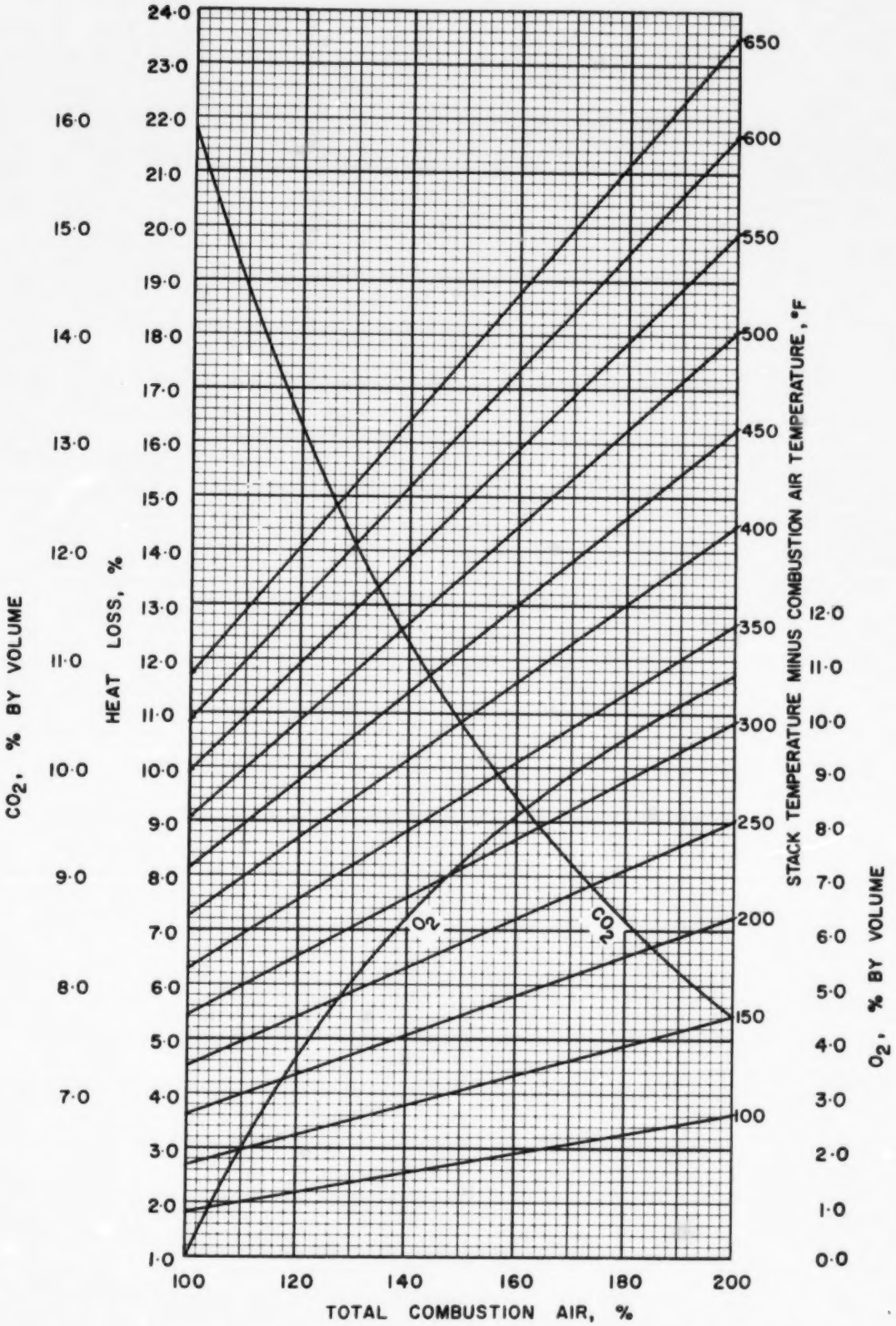
DRY FLUE GAS LOSS FOR A RANGE OF TEMPERATURE DIFFERENTIALS
FUEL: NATURAL GAS, 1007 BTU / CU FT

1007



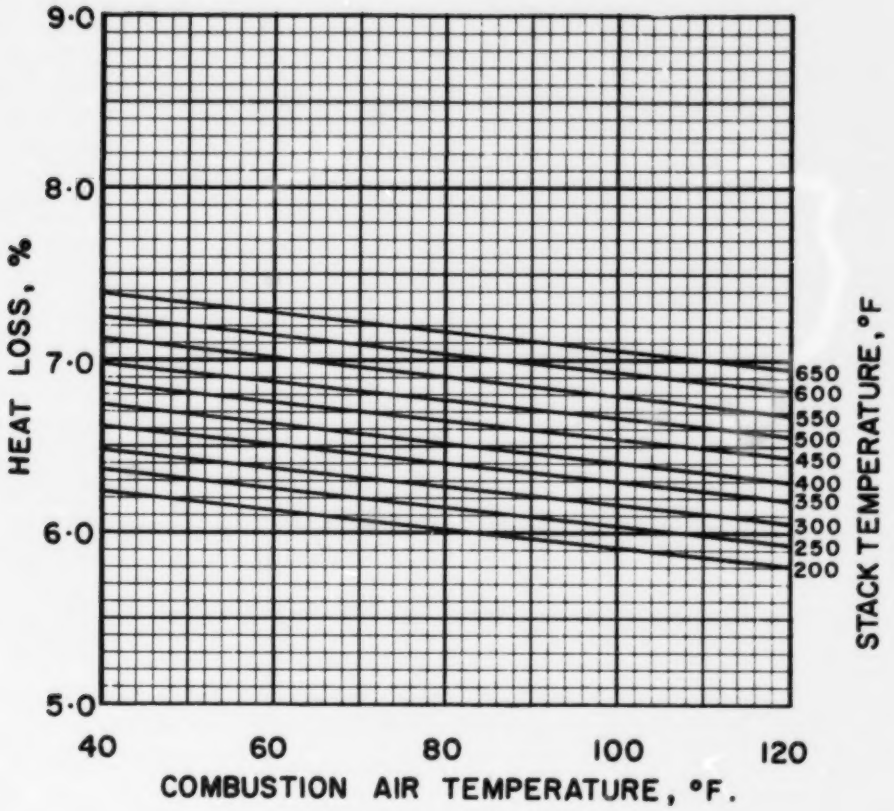
HYDROGEN LOSS FOR A RANGE OF STACK TEMPERATURES.

FUEL: NATURAL GAS, 1007 BTU/CU FT.



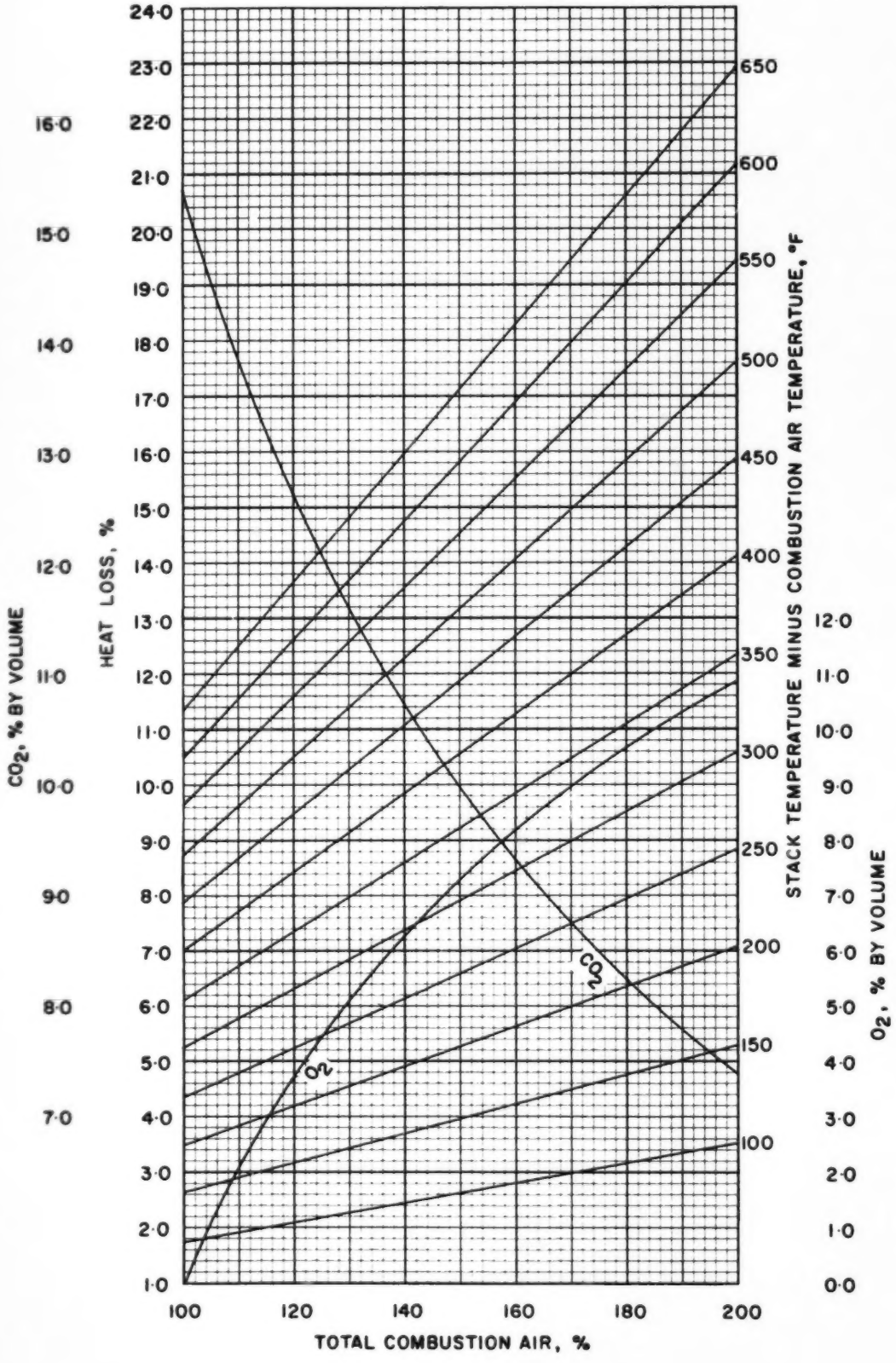
DRY FLUE GAS LOSS FOR A RANGE OF TEMPERATURE DIFFERENTIALS

(NO. 6 FUEL OIL)

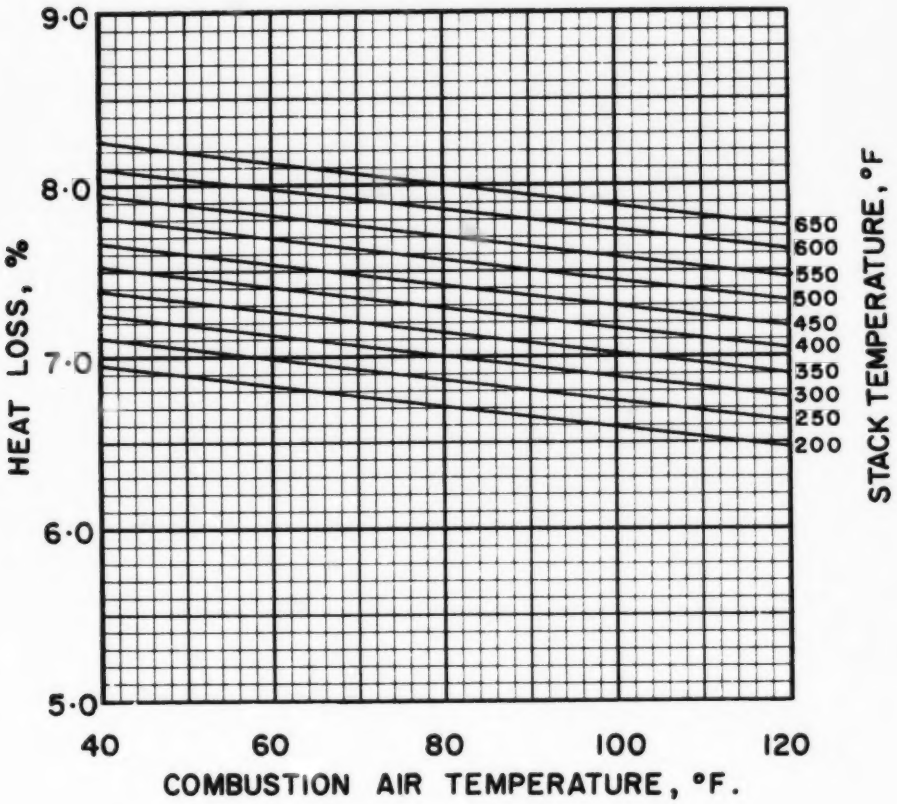


HYDROGEN LOSS FOR A RANGE
OF STACK TEMPERATURES.
(NO. 6 FUEL OIL)

9720

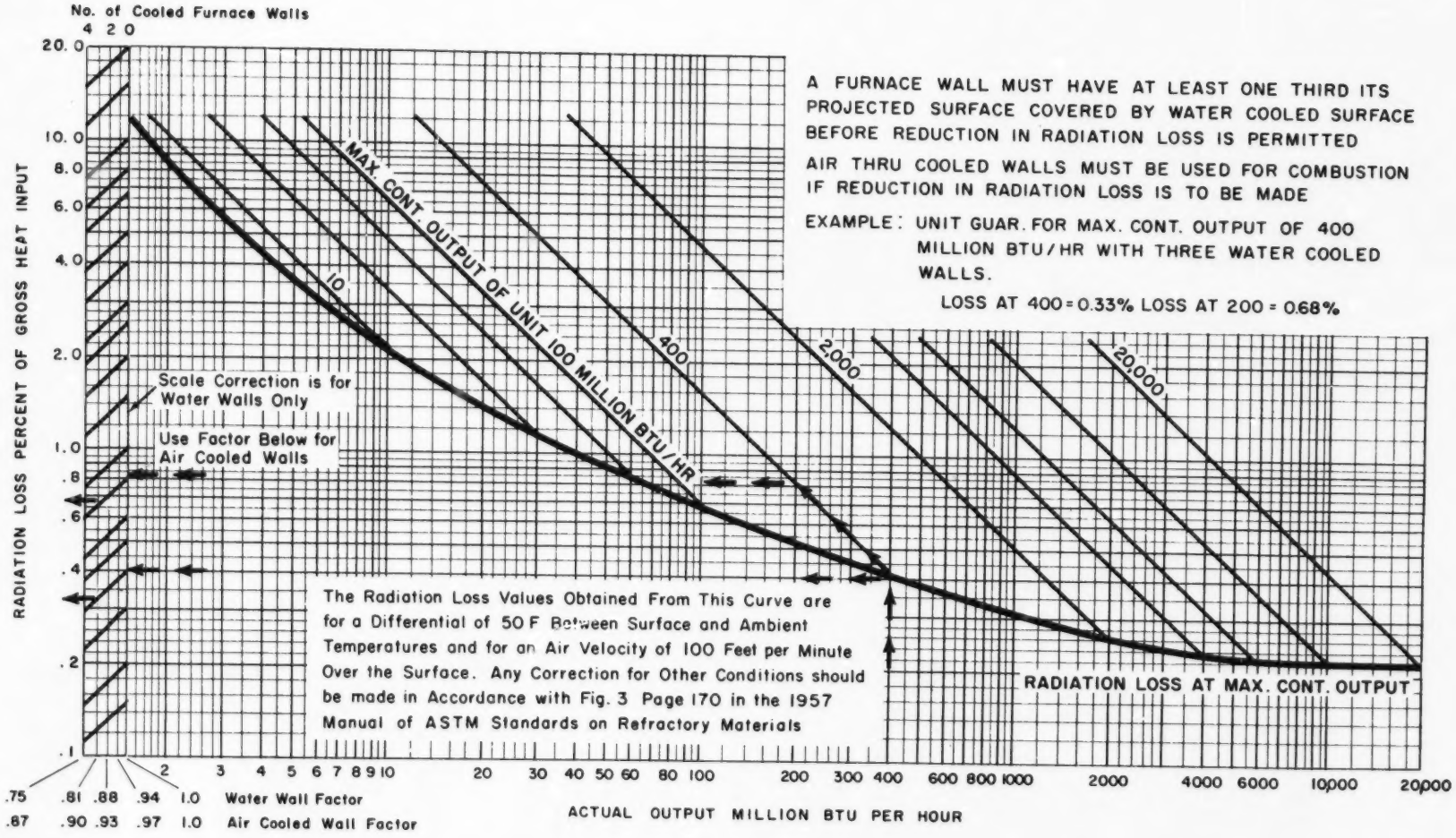


DRY FLUE GAS LOSS FOR A RANGE OF TEMPERATURE DIFFERENTIALS.
(NO. 2 FUEL OIL)



HYDROGEN LOSS FOR A RANGE
OF STACK TEMPERATURES.
(NO. 2 FUEL OIL)

8507


No. of Cooled Furnace Walls
4 2 0
RADIATION LOSS PERCENT OF GROSS HEAT INPUT
20.0
10.0
8.0
6.0
4.0
2.0
1.0
.8
.6
.4
.2
.1
MAX. CONT. OUTPUT OF UNIT 100 MILLION BTU/HR
10
400
2,000
20,000
Scale Correction is for Water Walls Only
Use Factor Below for Air Cooled Walls
A FURNACE WALL MUST HAVE AT LEAST ONE THIRD ITS PROJECTED SURFACE COVERED BY WATER COOLED SURFACE BEFORE REDUCTION IN RADIATION LOSS IS PERMITTED
AIR THRU COOLED WALLS MUST BE USED FOR COMBUSTION IF REDUCTION IN RADIATION LOSS IS TO BE MADE
EXAMPLE: UNIT GUAR. FOR MAX. CONT. OUTPUT OF 400 MILLION BTU/HR WITH THREE WATER COOLED WALLS.
LOSS AT 400 = 0.33% LOSS AT 200 = 0.68%
The Radiation Loss Values Obtained From This Curve are for a Differential of 50 F Between Surface and Ambient Temperatures and for an Air Velocity of 100 Feet per Minute Over the Surface. Any Correction for Other Conditions should be made in Accordance with Fig. 3 Page 170 in the 1957 Manual of ASTM Standards on Refractory Materials
RADIATION LOSS AT MAX. CONT. OUTPUT
2 3 4 5 6 7 8 9 10 20 30 40 50 60 80 100 200 300 400 600 800 1000 2000 4000 6000 10000 20000
ACTUAL OUTPUT MILLION BTU PER HOUR
.75 .81 .88 .94 1.0 Water Wall Factor
.87 .90 .93 .97 1.0 Air Cooled Wall Factor

RADIATION AND CONVECTION HEAT LOSS CHART, ASSUMING EMISSIVITY = 0·95
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